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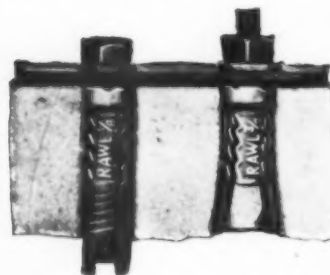
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The British Journal of Metals

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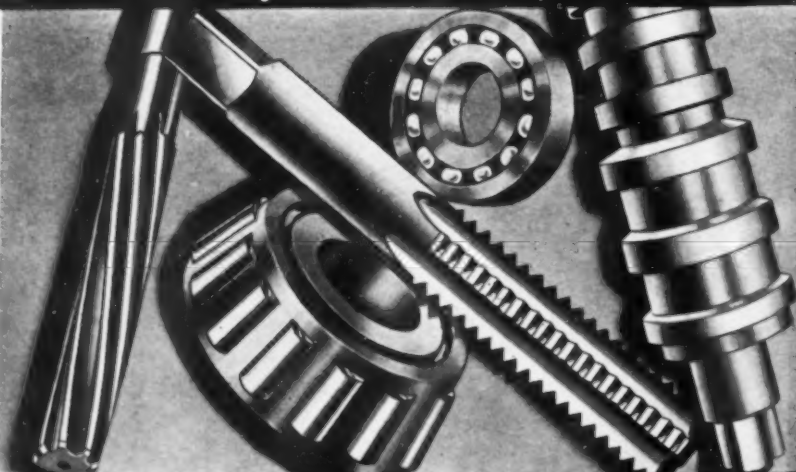
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Medium Manganese Steels in the Foundry

By H. Taylor, B.Sc.

Medium manganese steels refer to those carbon steels containing from 1.0 to 3.0% of manganese; they are pearlitic, and are distinct from high, austenitic, or Hadfields' manganese steel. In the normalised and tempered or water-quenched and tempered conditions steels of this type possess fairly high strength with excellent ductility, and in this article their application for castings is recommended.

MANGANESE, when added to a steel in an amount in excess of that required for the conversion of sulphur to manganese sulphide and for thorough deoxidation, is a true alloying element. Manganese not only forms complex iron-manganese-carbides, but a solid solution of manganese and iron. It has the effect of reducing the carbon content required to form the eutectoid—0.75% carbon, for instance, forms the eutectoid when 2.0% of manganese is present. It lowers the A_{r1} point; each 1.0% of manganese reducing the critical range about 35° C. Manganese also increases the hysteresis.

Reference to Guillet's diagram for manganese steels, shown in Fig. 1, shows the ranges of austenitic, martensitic, and pearlitic steels. The austenitic area contains the well-known Hadfields' manganese steel; the martensitic range embraces steels which are hard and brittle, and which up to the present have proved to have little commercial value; the pearlitic range, however, include the medium manganese cast steels, which provide an economic range of alloy cast steels, and it is this range to which particular reference is made in this article.

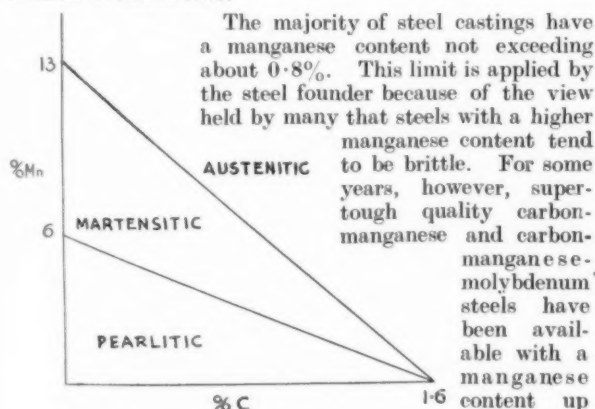


Fig. 1.—Diagram for carbon-manganese steels after Guillet.

applied in the forged condition, and in this country their development in the form of castings occupies a relatively small field.

The old belief that the higher manganese content was the cause of brittleness of steels was probably due to the fact that the ferro-manganese used in their manufacture was a product of the blast-furnace and contained relatively high carbon, consequently it was difficult to increase the manganese content of a steel while maintaining a low carbon content. By the use of modern methods, however, low carbon ferro-manganese and silico-manganese are now available to the steelmaker, and the difficulties formerly encountered in the manufacture of medium manganese

steels no longer apply; actually they are readily made in converters, open-hearth or electric furnaces.

From many points of view the medium manganese steels are valuable in the foundry. They have a high fluidity, and sections of $\frac{3}{16}$ in. thickness are successfully cast. A further advantage of this high fluidity is that while a fairly heavy primary pipe is formed in the heads, there is little or no secondary piping, which so frequently causes trouble. By comparison with castings in plain carbon steel there is a noticeable reduction in the number of hot tears.

Metallurgically, the steels are exceptionally clean. This doubtless is due to the excess manganese present during the deoxidation period, which causes the formation of complex silicates high in manganese as the products of deoxidation. These high manganese silicates have a low melting point and a high power of coalescence, and, as they form in large particles, they rise rapidly through the bath to the slag.

In the normalised and tempered condition these steels possess fairly high strength with excellent ductility. In the hardened condition of medium Brinell hardness they compare favourably in service with some more highly alloyed steels, and castings possess much greater toughness and resistance to shock than carbon steel castings of similar strength.

In the manufacture of medium manganese steels by both open-hearth and converter processes, low carbon silico-manganese is used to kill the bath, and after a suitable time is allowed to elapse to permit this action, the balance of the manganese is added in the form of ferro-manganese. During the tapping of the metal further deoxidation is effected by the addition of calcium-manganese-silicon alloy and/or aluminium to the ladle.

Heat-Treatment and Physical Properties

Two particular steels under consideration had the following analysis:—

	C.	Si.	Mn.	S.	P.	Ni.
A	0.26	0.47	1.31	0.036	0.038	0.73
B	0.24	0.47	1.20	0.037	0.038	—

In the as-cast condition both steels showed a very fine Widmānstatten structure; the microstructure of steel A is shown in Fig. 2.

Each steel was given the following heat-treatment: 950° C. for 4 hours, when the furnace door was raised and the sample allowed to remain in the furnace until the temperature had dropped below 600° C. This treatment breaks down the original cast structure and produces fine grains which readily go into solution when heated just above the A_{c3} point. The samples were then heated to 850° C., held at that temperature for 4 hours, and then air-cooled. The microstructure of the samples so treated are shown in Figs. 3 and 4. In both steels it will be noted the resultant structure comprises fine grains of ferrite and sorbitic pearlite; the steel containing nickel possessing a slightly

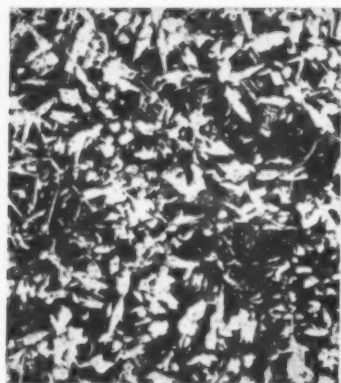


Fig. 2.—Steel "A" as cast.
× 50.

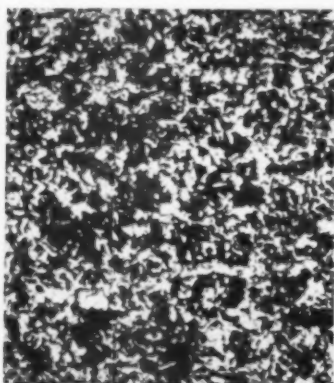


Fig. 3.—Steel "A" after
heat-treatment. × 100.



Fig. 4.—Steel "B" after
heat-treatment. × 100.

finer structure. The results of mechanical tests on the two steels are given in the following table.

	Yield-point, Tons per Sq. In.	U.T.S., Tons per Sq. In.	Elong. on 2 in.	Reduction in Area.	Bend, 1 in. × 1 in. on 1 in. Rad.	Izod, Ft.-lbs.
A	27	43.5	25%	48%	180° (N.B.)	22
B	22	39.5	29%	50%	180° (N.B.)	20
Water Quenched, 850° C. Tempered, 650° C.						
A	54	60	19%	42%	60°	52
B	40	48	21%	46%	80°	39

The question of normalising steel castings has long been a controversial one. The chief objection to the practice seems to be that residual stresses are left in the casting, due to irregular rates of cooling of the various sections. But the same argument can be as readily applied to forgings, yet thousands of medium manganese steel forgings are normalised without serious results. Small castings of regular section can safely be left in the normalised condition. Where there is a danger of residual stresses causing distortion during subsequent machining operations, a low-

temperature stress-relieving treatment may be given which will not affect the beneficial properties resulting from the normalising treatment.

The majority of foundrymen seem to be under the impression that a full anneal is the only treatment for steel castings. Tensile strength, elongation and bend properties seem to be the main factors to develop in a steel casting; the shock resistance capacity of a casting is too frequently overlooked, yet it is in this direction that the normalising treatment effects a great improvement.

Full annealing does not develop the excellent properties these medium manganese steels are capable of producing. They can even be given a water quench with comparatively little danger of cracking, unless the design of the castings is particularly intricate. This treatment, followed by tempering at a temperature determined by the use for which the casting is intended, develops outstanding ductility and resistance to impact. After tempering, medium manganese steels should be cooled rapidly to obtain the best impact values.

For most applications the carbon content of these steels should not exceed 0.4% with a manganese content under 1.8%. It should be noted that the cost of these steels, in comparison with other low alloy steels, is low, and their properties bear favourable comparison.

The Influence of the Quenching Medium upon the Hardening of Steels

THE demands on the quenching medium, from the point of view of the steel to be hardened, have been determined by the behaviour of the steel with regard to the transformation process. This process could be analysed by measuring either the through-hardening, the critical cooling rate, or best, the speed of the transformation, dependent on the temperature. The results of such tests are reported by Rose* for some typical steels.

The cooling capacity of the quenching medium can be illustrated expediently by representing the cooling rate of a solid of standard size and quality, plotted against temperature. Many publications show how such curves can be calculated, based on the changes of the temperature during the cooling period, and how they can be used for characterising the effect of quenching media. The author of the present communication, in collaboration with F. Wever, has developed a procedure of recording such curves in a simple manner.

The cooling capacity of liquids is influenced by three processes: (a) Formation of a film of vapour, the well-known Leidenfrost phenomenon; (b) boiling; and (c) conversion. The liquids can be characterised by the ranges of temperature of these processes and the individual cooling rates. The curves show this behaviour correctly.

The peculiarities of water as a quenching medium are the high cooling rates and the instability of the vapour film. There is a great difference between mineral and vegetable oils. The cooling rates are higher for the latter, and an equal boiling process covers a great range of temperature. The differences of the individual mineral oils result from their physical properties, not from the chemical analyses. There is a gap between the quenching capacities of water and of oil, and this can be bridged by means of emulsions or solutions of pectin, araban, or water-glass. As solutions of water-glass permit a wide range of cooling capacities by varying concentration, they can be used for hardening tests to show that the thermic analysis of a quenching medium, as described, corrects the hardening effect on steel specimens.

In order to obtain figures of the cooling capacity, independent of the special circumstances of the tests, heat-transition figures are calculated from the test results for the three cooling processes and for the individual quenching media. These figures are compared with numerous figures taken from the results of other workers, and it is surprising to find a good conformity in spite of the different conditions of the experiments.

A summary of the heat-transition figures of all investigated quenching media at 500° C. show that the whole range from 0 to 15,000 kcal/m² × hour × degree C. can be bridged by these media without a gap.

*Adolf Rose, *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung zu Düsseldorf*, Vol. XXI, No. 11.

Cast Iron Containing Copper

The use of different alloying elements in grey cast irons is steadily increasing. Modern trend is to pay close attention to carbon and silicon contents and strive for a balanced composition, adding two or more elements in combination to improve the physical properties. Successful results have been obtained by using copper, and investigations have produced some useful data which are of particular interest.

THE use of individual alloying elements to improve the properties of grey cast irons is well established, and the use of alloy cast irons containing different alloying elements is steadily increasing as the result of extensive study by the producers of these elements, as well as by ironfounders themselves. The tendency to-day is to pay close attention to carbon and silicon contents and to strive for a balanced composition, using, if necessary, two or more alloying elements in combination, to obtain the desired results in the most economical manner. Copper is, comparatively, a newcomer in the group of elements used as alloy additions to cast iron, but successful results have been obtained with it in several large foundries. Systematic data are required, however, by foundrymen interested in the production of copper alloy cast irons, so that the results published recently,* based on work carried out by C. H. Lorig and E. C. Kron, dealing with electric furnace cast irons containing copper, and forming part of a long-time programme of research and development on such irons being undertaken at the Battelle Memorial Institute, are of interest.

In the investigation dealt with, experiments were made on the effects of copper on the properties of grey cast irons of different carbon and silicon content and were planned to cover a wide range of compositions, so that an indication might be obtained of the inter-relations of carbon, silicon, and copper in cast iron. The various series of cast irons experimented with were prepared in an indirect arc electric furnace under carefully controlled conditions. Each charge was heated to about 1,540° C. in the furnace, poured into ladles, held until the temperature had dropped to 1,400° C., and then cast.

Four series of cast irons were prepared. There were a high carbon series containing 3.3 to 3.44% carbon, 0.63 to 2.5% silicon; a medium carbon series with 3.07 to 3.20% carbon and 0.68 to 2.61% silicon; a low carbon series with 2.8 to 2.9% carbon and 1.09 to 2.52% silicon; and an alloy series containing 3.12 to 3.23% carbon and 1.48 to 1.74% silicon, with various combinations of nickel, chromium, molybdenum and vanadium. The influence of copper up to 3% on each of these series was studied by determining the mechanical properties, tensile and transverse strengths, the deflection, the resilience, the Brinell hardness, and the impact resistance for four different casting sections represented by test-bars 0.875 in., 1.2 in., 2.0 in., and 4.0 in. diameter.

In the high-carbon series tests were made on 22 irons divided into five silicon groups. The trend in tensile strength, transverse strength, and Brinell hardness was found to be upwards with increasing copper content, and the deflection was affected only slightly, becoming lower as the copper content increased. The influence of copper was equally effective in the four sizes of test-bars, and the changes were characteristic for each silicon group of the series. The tests of the medium carbon series also consisting of 22 irons divided into five silicon groups, showed the general level of the properties in this series to be higher than that of the high-carbon series, due to the difference in carbon content. The trend, however, for the effect of copper was the same for both series. The mechanical properties of the low-carbon series, investigated in 16 irons

divided into four silicon groups, showed the tensile strength and Brinell hardness to increase with increasing copper contents, and the transverse strength and deflection to decrease with an increase in copper. Copper had little effect on the irons of this series, containing 2.48 to 2.52% silicon, except to increase the Brinell hardness.

The alloy irons studied, some 24 in number, contained from 3.12 to 3.23% carbon, and from 1.48 to 1.74% silicon, and these composition ranges were the same as for one of the groups of the medium carbon series of irons. Nickel, chromium, molybdenum or vanadium were added alone with the copper or in such combinations as nickel-chrome-copper, chrome-molybdenum-copper, nickel-molybdenum-copper, nickel-vanadium-copper, molybdenum-vanadium-copper, chrome-nickel-molybdenum-copper and nickel-molybdenum-vanadium-copper. Tests showed most irons of this series to have unusually good properties. There was little choice among them from the standpoint of tensile strength, and the small difference in properties which occurred indicated that by judicious choice of the proper elements some relatively simple compositions could be used to obtain tensile strengths similar to those secured by more complex and expensive combinations. Very effective simple combinations of alloying elements were copper-molybdenum, copper-chromium, and copper-vanadium.

The broad range of silicon contents covered in the various series of irons made it possible to determine the influence of copper on chill formation. Step bars and chill test castings were sectioned, etched to show the chill and mottling, photographed, and Brinell and Vickers hardness determinations made. These tests showed that copper was a mild chill reducer and that it raised the hardness of the grey areas of the castings. Because of their lower carbon contents, the irons of the medium carbon series showed a somewhat greater tendency to chill formation. In the low silicon irons, which were highly susceptible to chill, an increase in the copper content not only reduced the chill and mottled areas, but also the shrinkage, due to reduction in shrinkage going hand in hand with reduction of chill, because of the greater liquid shrinkage of white iron as compared with grey iron. The results obtained confirmed the belief that copper exerts a beneficial effect on the density of cast iron in heavy sections. Copper also tended to reduce the chill and to promote graphitisation in the low-carbon series of irons. In the lower range of silicon contents the influence of copper was pronounced, but its effect diminished rapidly in irons containing more than 2% silicon. In all the series of irons tested there was no indication of copper promoting chill in the higher silicon irons.

In general, the results of the investigation indicated the utility of copper, either alone or in simple combination with other alloying elements, as an alloy addition to cast irons. The addition of 1 to 2% of copper to the usual grades of engineering cast irons resulted in an increase in tensile and transverse strengths and in Brinell hardness. The tendency of copper to lower the values for tensile deflection increased as the carbon content of the iron was lowered. This property was not pronounced in the irons of the higher and medium carbon series, containing about 3.4 and 3.1% carbon. The desirability of a balanced composition with due regard to the copper, silicon and carbon contents to obtain the best combination of properties at the lowest cost was shown by the investigations carried out.

* T. F. Barlow, *Metals and Alloys*, 1940, Vol. 12, No. 1, pp. 26-39, and No. 2, pp. 158-159.

Correspondence

Electro-Plated Tin as a Finish for Brass and Copper-Rich Alloys

The Editor, METALLURGIA.

Sir,—While Mr. E. E. Hall's article, in your October issue, contains some interesting data on the corrosion-resistance of electro-deposited tin coatings, I cannot but regret that he appears to be entirely unacquainted with the latest developments in tin-plating practice. He has used for his tests plating baths which we believed had passed almost completely out of use, and which are not only difficult to control, but are incapable of giving coatings of the best protective value.

There are in very general use to-day two simple and reliable tin-plating baths—the alkaline sodium stannate bath, worked with filmed tin anodes, and the acid cresol sulphonate bath. The former is used without addition agents, while the latter requires additions of naphthol and gelatine. The alkaline bath is the more widely used, as being, perhaps, the simpler to control, but the acid bath has many adherents on account of its high electrical efficiency and the fact that it is used cold. With both solutions sound, continuous, strongly adherent coatings of any thickness can be obtained with certainty. Since the development of these baths, tin-plating has been increasingly used, not only for "small components of brass, bronze and copper," but for such articles as refrigerator coils, wash-boilers, and large vats and cooling plates for the food and dairy industries. Some of these vats, made of iron and steel, have been successfully plated, with coatings 0.002–0.010 in. thick. In these instances the resulting coatings have greater durability than the best hot-dipped coatings, which are always considerably thinner.

All these baths are fully described in our publication No. 92, "Electroplating. Working Instructions," and a copy is enclosed which I ask you to pass on to Mr. Halls, in the hope that it will help him to pursue his excellent work on the value of electro-tinned coatings.—Yours faithfully,

(Signed) W. H. TAIT,

Technical Development Manager,

International Tin Research and Development Council.

Fraser Road,

Greenford, Middlesex,

October 25, 1940.

The Editor, METALLURGIA.

Sir,—I am familiar with the excellent publications of the International Tin Research and Development Council, covering electro-tinplating, and in particular with No. 92, which gives practical working conditions of the latest recommended processes.

The fundamental point of the article was to establish the durability value of tin electroplate coatings for copper-rich non-ferrous alloys. Again, I had in mind that miscellaneous collection of articles encountered in the industrial finishing shops of the engineering industries. The electrical, light electrical, radio, instrument and similar trades amply illustrate this field. The work consists of blanks and pressings, mechanical components from rod and bar, castings, and so forth. Size, configuration and mass vary tremendously in work treated during the day. The plating shops concerned, it is considered, have a more arduous task than those handling large quantities of a few types of article. This explains probably why a large number of plants still operate on old formulae or upon formulae devised from their own experience.

The data given to demonstrate durability of electro-tin coatings were compiled, using actual articles plated from two selected commercial baths. The tests were extended over a period of many months. At the outset of the work, one of the baths, alkaline stannate using nickel anodes, represented an up-to-date method. It differs from the most recent process essentially in using inert anodes instead of

filmed tin anodes. The nickel anodes emerged from the work of experts both in America and this country, in an attempt to overcome defects using tin anodes; they proved entirely a success in this. Filmed anodes and the associated technique and control achieve a similar end. Nevertheless, it is significant that a large number of important factories in America still prefer the nickel-anode process. It has advantages of ease of control, rapidity and wide range of current density concordant with good results with respect to soundness and to appearance. This flexibility of current density is a very important feature when handling a miscellany of work, and still more so if the plant used is semi or fully automatic. The particular alkaline stannate formula quoted represents one worked out in practice and considered to give best results on the class of work in question.

The following plating solutions are also still in use with large concerns:—

(a) Electrolyte:—

Sodium Stannate	30.0 oz.
Resin	0.04 ..
Water	1 gal.
Temperature	65°–70° C.
Plant	Still vat or horizontal barrel
Cathode C.D.	15 amps./sq. ft.
Voltage	4 to 6 volts for vats, 9 to 12 volts for barrels
Anodes	Tin

(b) Electrolyte:—

Stannous Chloride	5.0 oz.
Caustic Soda	15.0 ..
Glue	0.65 ..
Temperature	70°–85° C.
Plant	Oblique barrels
Cathode C.D.	Controlled by voltage
Voltage	9 to 12 volts
Anodes	Tin

I am afraid general industry is rather slow always to accept research results, and grant that such tardiness is often not justified. However, the problem of converting existing practices is quite a different one from that of simultaneously introducing the newer methods with new applications, as many of the instances quoted by Mr. Tait seem to be.

In conclusion, I would again stress that the fundamental object was to establish the merits of good tin electroplate coatings. The article was intended as an independent observer's contribution to the knowledge on tin coatings, and it is trusted it will in no way be interpreted as belittling the work of the International Tin Research and Development Council. The latter invariably calls for admiration in its conciseness, clarity, accuracy, and utility.—Yours faithfully,

New Barnet, Herts.,

October 30, 1940.

E. E. HALLS.

Railings for Scrap

The Iron and Steel Control of the Ministry of Supply has inaugurated a new voluntary scheme to encourage the private owner to give up his railings for the scrap-metal campaign. A start has been made in the Midlands area—Leicestershire, Shropshire, Staffordshire, Warwickshire and Worcestershire,—with Birmingham as the centre, and the scheme will be extended to other districts as soon as results from the Midlands area are received.

The actual work of removal can be carried out either by the local authorities, who would then make good walls and copings, or put out to tender by scrap merchants. Although the price of scrap metal is controlled, it is high enough, when the metal is handled in reasonable bulk, to cover costs of removal and making good walls, and also to leave an amount over. This excess can be applied to the relief of rates, or handed over to the Red Cross or other voluntary appeals.

The Iron and Steel Control is prepared to advise on suitable scrap-metal merchants for the purpose, or to give location of plants to which broken-up metal may be sent if the local authorities prefer to carry out the breaking-up, sorting and disposal themselves.

METALLURGIA

THE BRITISH JOURNAL OF METALS.
INCORPORATING "THE METALLURGICAL ENGINEER"

Leadership in Industry

MUCH could be written in attempting to define a leader of industry, but this is no more possible than it is to define an artist; even if it were possible no useful purpose would be served. It is proposed, however, to direct attention to the importance of efficient leadership and to the strange lack of facilities in this country for adequate training. In the past we have depended mainly upon those who had a particular flair for leadership, and it is probably true, as with artists, musicians, sculptors, etc., that great leaders in industry are born and not made, yet surely training is just as essential to bring out the best in the individual as it is to the potential artist, musician or sculptor.

In earlier days industrial conditions were not so exacting and competition not so acute as in recent years, and the attributes of leadership did not then require to be so great as they are to-day. Increasing keenness in competition has reduced the margin of profit, while the demand for better quality products has been continuous, and both design and manufacturing technique has become more complex. Coupled with these developments has been the gradual improvement of the industrial population; improved general educational facilities have assisted in the demand for a higher standard of living, while there has been continual pressure to reduce working hours and to bring about better working conditions. Industrial production has of necessity been increased to a magnitude that has tested not only the ingenuity of men, machinery and management, but also of organisation, direction and leadership. Applied in the direction of co-ordinating effort, organisation is the first step towards industrial planning; this, in turn, is the precursor of systematic production. The part that leadership plays in the whole system is admirably discussed by Mr. Wilfrid Ayre, in his presidential address to the members of the Institution of Engineers and Shipbuilders in Scotland, and his views on the subject are worthy of particular note.

Whatever value we may have in the past attached to the attributes of leadership in industry, said Mr. Ayre, the course of the present war to date has proved unmistakably that these qualities are now of first importance. This does not only concern the production of war material or even particularly shipbuilding or engineering; it is true of every decision that requires to be taken in the essential interests and security of the nation. In times of peace, those responsible for directing industry pit their organising, productive and commercial ability against contemporary competition from wherever it may come, and, according to the degree of enterprise and leadership displayed in each unit of industry, efficiency, in the end, outstrips inefficiency.

When total war comes, necessity demands production on an unprecedented scale with an increased rate of output. It is then not unusual to find either that manufacturing methods acceptable for a peace-time standard of output are totally inadequate for war-time emergency or that there is insufficient flexibility to permit the adoption of a rate of production far beyond the normal capacity of the works. In such conditions, leadership in industry must be entrusted with the task of stimulating imagination, applying foresight and exhibiting genius . . . yes, and imparting vigorous action in solving the new problems thus created, always with the object of procuring utmost production.

Organisation and leadership are the nerve centres of industry; competition in peace-time, their activating force. Without them no industry can survive. Competition can never be eliminated from commerce, and efficiency of organisation—coupled with enterprise—will always favourably decide the competitive issue. Leadership in general does not merit the loose eulogies sometimes given to personages associated with the control of industry. Leadership is a virtue of industry and the real driving force behind all organisation; it demands the energy, will and enthusiasm to develop every material resource, actual and potential, of which any unit of industry may be possessed. An inert or tradition-bound attitude towards the day-to-day problems of organisation, production, finance or salesmanship, can never command the maximum economic result, or hope to raise the status of executive or administrative authority to the highest level—that of leadership.

Indeed, war-time experience has proved in innumerable instances that peace-time standards and practices of industrial management, direction, leadership and outlook completely fail to drive the machinery of production at that overload speed and capacity which emergency conditions demand. In these circumstances, only leadership and direction of the highest calibre will successfully push production towards peak level and succeed, by an unswerving degree of control, in maintaining it there.

When executiveship fails to do so, then leadership must initiate technical progress, if only because the duties and responsibilities which belong to it bring more opportunities of becoming aware of the potentialities and requirements of industrial production than perhaps any other rank in an industrial organisation. At no time is technical knowledge of greater value than when business negotiations are actively in progress. The ability to discuss, and dispose of, any technical problems that may arise on the spot rather than to "refer back to the works" often outwits competition and results in a speedy and fruitful conclusion of business negotiations.

But technical knowledge is only one of the many attributes of leadership; the production problem in industry demands and deserves a large share in the functions of leadership. The application of modern production methods, for instance, often encounters opposition from within, but their unquestionable efficiency, if pressed home, will usually succeed in ridding a works of malpractices which in too many instances are responsible for retarding output. The problem of labour control and management is another obvious and important responsibility of leadership. Mere supervision is not enough.

Under present conditions there are but restricted opportunities available to promising young men, not yet risen to positions of responsibility, for acquiring knowledge of, or experience in, the problems of organisation, production and commerce. Furthermore, the facilities available for technical education provide little or no opportunities for the study of, or acquiring proficiency in, commercial and administrative problems of industry, such as accountancy and commercial law, production control and functions of management, salesmanship and general principles of business policy. The provision of such facilities is long overdue, and should be established on a sound basis without delay, because only real ability, driving force, and the makings of leadership will and should succeed in the future.

Secondary Non-Ferrous Metals

THE increasing demand for non-ferrous metals resulting from war conditions has directed greater attention to the use of scrap metal in its various forms. For many years the United States Bureau of Mines has recognised the need for data regarding the consumption of secondary non-ferrous metals, and has made an annual survey of the subject. In the recent survey, covering 1939, it was considered that additional information was desirable, and the schedules were designed to give a separation of "new" and "old" scrap and to include stocks of each item of scrap on hand at the beginning and end of the year. New scrap is defined as the refuse produced during the manufacture of articles for ultimate consumption, including all finished and semi-finished articles that are to be reworked. It includes defective castings, cuttings, punchings, turnings, borings, skimmings, drosses, slag, etc. Finished and semi-finished articles are frequently returned as scrap because of faulty manufacture, excess production, change of design or other cause of obsolescence. Old scrap is defined as scrap derived from metal articles which have been discarded after serving a useful purpose.

The return of metals from use exerts a profound effect upon the metal mining and the primary metal-producing industries, and the Bureau of Mines' revised survey has been designed to demonstrate the relationship of new and old scrap and to assemble basic data of value to the expanding secondary metals industry. Nearly 100 classifications of scrap were used in the survey, and companies reported their purchases of each item separately. Recoverable metal contents of each item of scrap were calculated from average assays of each item, and in this manner the total quantity of recoverable metal was determined, regardless of the form in which the metal was ultimately reused.

Secondary Aluminium.—Aluminium recovered from scrap in 1939 amounted to 50,000 short tons, of which 50% was derived from castings; 27% from various types of scrap sheet; 7% from borings and turnings; 6% from new aluminium clippings; 2% from wire and cable; and 8% from miscellaneous materials. Aluminium recovered at the plants of remelters amounted to 39,700 tons, while manufacturers and foundries accounted for 10,300 tons of the total aluminium recovered.

Secondary Antimony.—Antimony recovered from secondary sources amounted to 9,810 short tons, consisting of 9,520 tons recovered in lead base alloys, in oxide, and as metal; and 290 tons in tin base alloys. Discarded lead storage batteries accounted for 58% of the recovery; antimonial lead, common babbitt, type metals and drosses accounted for 39%, while scrap tin alloys accounted for 3%.

Secondary Copper.—Copper recovered from scrap amounted to 499,700 short tons, of which 151,370 tons was recovered as essentially pure metal, 162,400 tons in brass, 182,730 tons in alloys other than brass, and 3,200 tons in chemical products. Of the total copper recovered, 43% was derived from items of brass scrap; 28% from items of copper scrap, including various grades of wire, 23% from composition and bronze alloys, including automobile radiators; and 6% from miscellaneous items. Copper recovered at plants of remelters, smelters and refiners amounted to 237,700 tons, while manufacturers and foundries accounted for 262,000 tons.

Secondary Lead.—Lead recovered from scrap metals amounted to 241,500 short tons, of which 86,900 tons was in the form of refined lead and 154,600 tons was in alloyed form. Discarded lead storage batteries accounted for 51% of the total recovered, while recoveries from other sources were as follows:—13% from soft lead, 9% from cable lead, 8% from drosses and residues, 6% from alloys other than lead, 4% from common babbitt, 3% from solder, 3% from hard lead, and 3% from type metals. Remelters, smelters and refiners accounted for the recovery of 206,900 tons, while manufacturers and foundries accounted for 34,600 tons.

Secondary Nickel.—Nickel recovered from scrap metals amounted to 2,920 short tons, of which 60% was derived from nickel silver, 15% from pure nickel clippings, nickel anodes, hangers, baskets, etc., 12% from iron alloys, 11% from Monel metal, and 2% from stainless steel. Remelters, smelters and refiners accounted for 525 tons of the total nickel recovered, while manufacturers and foundries accounted for 2,395 tons.

Secondary Tin.—Total tin recovered from secondary sources amounted to 29,160 short tons, of which 4,460 tons was in the form of metallic tin, while 24,700 tons was in alloyed forms. Detinning plants accounted for 4,089 tons of the metallic tin recovered, and other sources contributed 371 tons. Scrap copper base alloys accounted for 43% of the total tin recovered, while 16% was derived from new tinplate clippings (including 0.3% from old containers), 16% from solders, 9% from tin scruff and drosses, 5% from common babbitt, 3% from No. 1 babbitt, 2% from block tin pipe, 2% from genuine babbitt and No. 1 pewter, 2% from type metals, and 2% from miscellaneous items. Remelters, smelters and refiners accounted for 13,410 tons of the total tin recovered, while manufacturers and foundries accounted for 15,750 tons.

Secondary Zinc.—Zinc recovered from secondary sources totalled 189,640 short tons, of which 35,970 tons was recovered in slab form, while 153,670 tons was recovered in copper base alloys and chemical products. The principal source of zinc recovered was secondary copper alloys, which accounted for 45%, zinc drosses and skimmings contributed 42%. Recoveries from other secondary sources were as follows:—5% from die-castings, 2% from clippings and sheet, 2% from flue dusts, and 4% from miscellaneous sources. Remelters, smelters and refiners accounted for 91,800 tons of the total zinc recovered, and manufacturers and foundries for 97,840 tons.

Systematic national stocktaking of the secondary metal resources is especially useful when a country is at war, and some organised plan to obtain similar data in Britain would have been of great value at the commencement of the present hostilities. Even at present it is very doubtful whether the best use is being made of Britain's secondary metal resources.

Import Licensing of Tin and Alloys of Tin

In future, licences to import tin and alloys containing more than 50% of tin will be issued on the advice of the Non-Ferrous Metals Control. Accordingly, applications for licences should be completed in duplicate and sent to the Non-Ferrous Metals Control, Ministry of Supply, Grand Hotel, Albert Street, Rugby, and not to the Import Licensing Department, as directed at the top of the form.

Forms of application may be obtained from the Import Licensing Department, or the Office of any Collector of H.M. Customs and Excise. Importers are reminded that there is an Open General Licence for the import of tin in blocks, slabs, ingots and bars from the British Empire (except Palestine, Hong-Kong and Transjordan).

Emergency Standard for Aluminium Bars

A WAR Emergency Standard B.S. 918-1940, has just been issued for aluminium bars containing small proportions of copper. This material formed the subject of a specification in the aircraft series L. 34, which has now been withdrawn and will be replaced by the War Emergency Standard; the scope of this emergency standard has been extended to apply to all branches of engineering. It is realised that there are still certain problems associated with the development of this material, and for this reason the specification has been included in the War Emergency Series. It will be the subject of review and modification after the end of the war.

Copies of this Specification may be had from the British Standards Institution, Publications Department, 28, Victoria Street, London, S.W. 1, price 2s. 3d. post free.

The Examination of Metals by Ultrasonics

By A. Behr, B.Sc.

Much work has been carried out in developing an ultrasonic method of testing metals, and recent references indicate that such a method is ready for application and to take a position with the more familiar X-ray and gamma-ray techniques. In this article is given a brief account of the development of the process and more particularly of its instrumental side, and of the principles underlying it.

A REFERENCE to the use of sound in testing metals usually evokes only the familiar picture of the wheel-tapper walking up and down the railway lines. This in fact was, with other similar tests, until quite recently the only application of sound to the non-destructive testing of metals. Such tests depend, of course, on the vibration of the part being tested and on the effect on such vibrations exercised by a defect in the part. While, with practice, it is no doubt possible to decide from the nature of the sound emitted whether a defect, such as a crack, is present or not, it is not possible to obtain any exact idea of its size and to determine its position.

It is somewhat surprising to find that the very considerable amount of work carried out in Russia during the past 10 to 15 years in developing the more "refined" ultrasonic method of testing metals has gone practically unnoticed. Recent references in the Russian technical press show that the process has already passed beyond the stage of a laboratory curiosity and is in fact ready to take its place alongside the more familiar X-ray and gamma-ray techniques. It has, therefore, seemed opportune to present a brief account of the development of the process and more particularly of its instrumental side and of the principles underlying it. A few introductory words regarding the nature and behaviour of ultrasonics may not be out of place at this stage.

The term "ultrasonics" is used in acoustics to denote the frequencies which are beyond the limits of hearing of the human ear—that is to say, frequencies of about 20,000 (20 kHz.) and upwards. Suitable methods enable ultrasonic vibrations with frequencies up to 5×10^5 kHz. to be produced. The laws of sound valid for the audible range are also true for the ultrasonic range, though in the latter case further phenomena appear which had not previously been observed in the audible range.

There are mechanical, thermal, magnetostriction and piezo-electric generators for ultrasonics. By the piezo-electric method, as well as by the magnetostriction method, high-frequency electric oscillations can be transformed into powerful mechanical oscillations.

Certain crystals, such as tourmaline, quartz, etc., when subjected to pressure or tension, develop electric charges on definite crystal surfaces. The electric charges set free are proportionate to the amount of mechanical pressure or tension. The sign of the charges changes when a compression of the crystal is changed into a tension. In a quartz crystal the maximum charges produced by mechanical stress only appear at the ends of a polar axis, and for this reason the plates or rods made use of are cut, as far as possible, out of the crystal in such a way that one pair of surfaces are at right-angles to a polar axis, frequently named the piezo-axis.

Alternatively, if a quartz plate is put in an alternating electric field in such a position that the direction of the field is in the direction of the piezoelectric axis, for example, by putting a quartz plate between the plates of a condenser connected to a source of alternating current, the quartz will be compressed in one half of the cycle of the field and

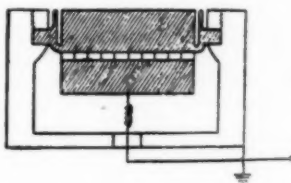


Fig. 1.—Generator.

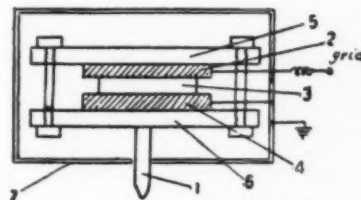


Fig. 2.—The piezo-electric detector.

expanded by the same amount in the other half. It will thus be set into elastic oscillations of the same period as the field. Their amplitude will be a maximum when there is resonance between the electric frequency and the natural mechanical frequency of the plate.

In order to avoid the use of large plates, a number of smaller quartz plates of equal thickness mounted between steel plates can be used, and this system can be set vibrating in its natural frequency.

As far as the spreading of ultrasonics sent out by a vibrating piezo-crystal is concerned, it exhibits the property common to all forms of vibration of an increased directionality as the wave-length of the vibrations is reduced. Thus, it is possible to obtain a quite sharply demarcated beam of ultrasonics which will leave in a direction normal to the vibrating surface producing them, provided the surface is large compared with the wave-length of the vibrations.

When sound passes from one medium of density ρ_1 , in which it travels at a velocity v_1 , into a second medium of density ρ_2 , where it travels with velocity v_2 , the reflection of the wave is given by

$$R = \left(\frac{\rho_1 v_1 - \rho_2 v_2}{\rho_1 v_1 + \rho_2 v_2} \right)^2$$

This gives us for the percentage of sound which is reflected from the boundary, water/steel, 86%; water/glass, 66%; oil/steel, 88%; oil/glass, 70%; and for mercury/steel, 11.5%. On the other hand, for the passage from liquid to air, or vice-versa, we get a value of 100%.

The only electrical receivers suitable for use in ultrasonic work are the piezo-electric crystals, since all other forms of microphone are too insensitive, at least for high-ultrasonic frequencies, on account of their great mass.

The action of piezo-electric receivers of ultrasonic vibrations is based on the phenomenon mentioned above, by which electric charges are set up on definite faces of piezo-crystals when they are subjected to a mechanical stress. Thus, if an ultrasonic wave meets the piezo-electric plate, the plate is set in mechanical vibration and the resulting mechanical deformation causes electric charges to be liberated on the surface at right angles to the X-axis by what is known as the direct piezo-electric effect. The sign of these charges, and hence the differences in potential produced with a given electrode capacity changes periodically with the frequency of the wave. This alternating voltage produced by the receiving quartz or other piezo-crystal can then first be amplified by means of a thermionic valve and then rectified by a second valve and made audible as a beat.

Metals in general exhibit a very good transmissibility for ultrasonics, provided they are completely homogeneous, but if there are holes, cracks or other discontinuities, a noticeable reflection and/or absorption of sound waves takes place at these interfaces in accordance with the reflection formula given above. This gives rise to the possibility of testing material by ultrasonics. In his book, "Ultrasonics and their Scientific and Technical Applications,"¹ L. Bergmann mentions that the first to point this out was Mühlhauser in a patent specification.² This inventor proposed to go over the mass of metal under test with an ultrasonic transmitter and receiver and to draw conclusions concerning defects in the interior of the metal from the intensity of the sound transmitted by it. It is interesting to note that a suggestion regarding the use of ultrasonics for this purpose was made in the literature some considerable time before the application for the above patent was lodged. This was in an article by the Russian investigator, Sokolov,³ to whom the credit for this invention must undoubtedly be given. In it he describes the generation of ultrasonics and their properties, and a number of experiments on the passage of ultrasonics through different media—in particular, metals. In experimenting with a copper cylinder 150 mm. in diameter and 200 mm. high, an excessive damping of ultrasonics in it was observed. On sectioning it, he discovered that the cylinder was inhomogeneous (full of casting defects). To quote Sokolov's subsequent remarks:—

"After that, different steel and cast-iron objects were investigated, and it was found that in this way cracks, inhomogeneities and inclusions could be detected. Ultrasonic vibrations can be used to amplify X-ray examination; in particular, they could be used to detect cracks and casting defects in large thick parts."

In his early work, Sokolov⁴ described the designs of ultrasonic quartz generators, and refers to the generator already mentioned, which is built up of a number of quartz plates mounted between two suitably suspended steel plates (see Fig. 1). In order to investigate the vibrations on the surface of this generator a special detector device was constructed, which consisted of a plate of Rochelle salt, a substance which exhibits the piezo-electric effect, between two metallic plates, one of these plates being connected to the grid of an amplifying valve, and the other to earth. The latter carried a glass rod attached by means of shellac, the other pointed end of which contacted the vibrating surface to be investigated, as shown in Fig. 2. Such an indicator is very simple and extremely sensitive, and enables a wide range of amplitudes over a wide frequency range to be investigated. The surfaces of the Rochelle salt crystal, and the two brass electrodes between which it is clamped, must be carefully polished, and preferably moistened with transformer oil. The whole is enclosed in a metal casing, through which the tip of the glass rod is passed.

An alternative detector instrument was also designed in which a variable contacting surface was provided. This enabled larger areas of the vibrating surface to be studied. A three-valve amplifier was used, designed in such a way that amplification should remain as linear as possible over the widest frequency range. Amplification was about 100. A valve voltmeter was used to measure the amplified potential.

In view of the fact that ultrasonic vibrations are practically completely reflected at a solid/air interface, the piezo-electric generator is usually immersed in a liquid. Ultrasonics generated in this way in a liquid will form a beam which will pass through various solids if these are

situated in their path. As the absorption of elastic vibrations in metals is very small, the vibrations will pass through a great thickness of metal, provided there are no cracks, blowholes, etc., which would stop them. This will, however, occur only if the wave-length of the ultrasonic vibrations is sufficiently small in comparison with the size of the blowhole or other defect as otherwise the ultrasonic waves will be able to curve round the obstruction.

The first type of generator described was of the type illustrated in Fig. 1, and consisted of two steel plates about 30 mm. thick, between which were cemented a considerable number of quartz plates of equal thickness. The surface of the top plate radiates the sound waves. A layer of mercury was placed within the confines of a ring on the upper steel plate, and served to carry the sound to the material under investigation. In the first instance, bronze and steel discs 220 mm. in diameter and from 30 mm. to 50 mm. thick were investigated. Use was also made of steel cylinders 100 mm. in diameter and up to 250 mm. high. The first experiments showed that vibrations would pass through all these bodies, and that the vibrations on the opposite, upper surface of the metal discs or cylinders were comparatively intense. The intensity of the emergent vibrations was gauged from the vibration of a layer of transformer oil poured on the upper surface.

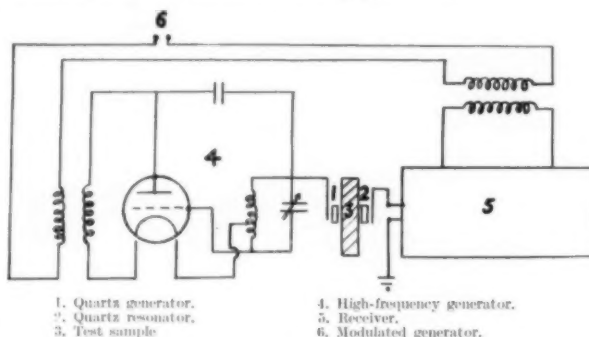


Fig. 3.—Detector circuit.

Further experiments were carried out on steel specimens 200 mm. in diameter and up to 700 mm. high. Vibrations on the upper surface of the 700 mm. high specimens were still clearly seen in the layer of transformer oil. Transmission through thicknesses of up to 1,000 mm. was obtained after placing the cylindrical specimens one on top of the other and moistening the surfaces in contact with transformer oil. If the oil was omitted, the vibrations would not pass. No vibrations could be made to pass through two specimens 30 mm. high, placed one on top of the other, the surface of contact of which had been left dry and ground to within 0.0005 cm. This showed that internal cracks with a thickness of the above order could be detected.

Studying the surface of the specimens, it was found that the maximum amplitude of the vibration occurred immediately opposite the transmitter and died away rapidly towards the circumference.

For easier observation, the transformer oil used was poured into a small dish with a flat bottom. This dish was placed on the surface of the metal, a film of transformer oil being placed between the two. To detect vibrations in the oil a beam of light was reflected from its surface on to a screen. Very slight vibrations on the surface of the oil would then cause distortion of the reflected spot of light.

In examining metal specimens for the presence of defects, use could be made of the above-mentioned optical indicator when the specimens were in the form of large flat plates. The position of cracks or surfaces of separation within the plates could be readily detected in this way.

Instead of the optical method, the piezo-electric detector illustrated in Fig. 2 could be employed. This detector, suitably screened, could be used to study the whole surface of the part under investigation, and thus determine at any

¹ "Ultrasonics and their Scientific and Technical Applications," L. Bergmann, Published by the V.D.I. Verlag, Berlin; English translation by H. Stafford Hatfield, (G. Bell and Sons, Ltd., 1938, London).

² German Patent 569,508, 10/1/1931, published 4/2/1933.

³ S. Ya. Sokolov, *Elektrische Nachrichten und Technik*, November, 1929, VI, pp. 454-461.

⁴ "Ultrasonic Vibrations and their Applications," S. Ya. Sokolov, *Zavodskaya Laboratoriya*, 1935, No. 5, pp. 527-528.

point the intensity of the vibrations passing through the metal. In doing this, the transmitter and the piezo-electric detector are rigidly connected together and moved over the specimen. This method can be used for detecting large blowholes, inclusions, etc. Regions in the metal consisting of a large number of small blowholes (porosity) have a particularly marked screening action on the vibrations.

In another method of examination the specimen is immersed in a tank filled with oil, in which the specimen can be freely moved along. The transmitter is placed some 1 mm. to 2 mm. below the specimen, the surface of the oil being adjusted to be 0 to 2 cm. above the upper surface of the specimen. The beam passing through the specimen causes the formation of ridges on the surface of the oil, these ridges or lines being characteristic of the ultrasonic beam. These lines can be made visible by reflecting a beam of light from the surface of the oil at that particular spot, the reflection being projected on to a screen. The appearance of the reflection will give a qualitative indication of the ultrasonic beam after its passage through the metal specimen and hence of the interior structure of the specimen. These reflections, with their characteristic light and shadow distribution, can be photographed to give what are referred to as "ultrasonograms" of the metal. With some experience, it is possible to use the line pattern in these

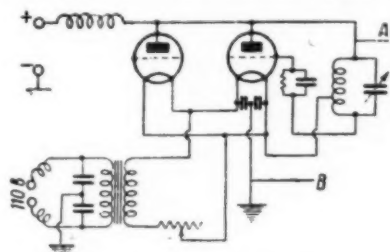


Fig. 4.—Circuit of high-frequency generator; A and B are points to which high-frequency voltage is applied.

photographs to gauge the presence of various defects and their distribution in the metal. There is also some connection between the temperature of the specimen and these patterns.

In a later article⁵ Sokolov deals more particularly with the distribution of the ultrasonic beam in the metal. Detailed investigations had shown the occurrence of scattering of ultrasonic waves due to multiple reflection from the outer boundaries, as well as from internal inhomogeneities in the metal. The presence of multiple reflections is particularly noticeable in small specimens. Scattering is also dependant on the structure of the metal. Thus, for example, with a fine-grained structure there is less scattering than in coarse-grained metal. In general, it must be pointed out that in metals we do not obtain the same degree of direction of the ultrasonic beam as is obtained in liquids, and this frequently gives rise to inaccuracies in detecting flaws. In order to avoid these drawbacks, and to have a method of examining small-size specimens containing small internal inclusions or flaws, a number of methods have been developed which eliminate the effect of multiple reflection from the boundaries of the specimen. These methods are based on the following principles:—If l is the thickness of the specimen, the time required for the ultrasonic beam to pass in a straight line from one face to the other if the metal is homogeneous will be $\frac{l}{c} = t$, where c is the velocity of the sound. If a flaw occurs in the path of the beam, the time to pass from one face to the other will be different—e.g., t_1 , where t_1 is greater than t , as the beam will have to pass round the flaw and cover a greater distance. If cognisance is taken of this fact in one way or the other, the presence of the flaw will become known.

The circuit illustrated in Fig. 3 was used for the purpose of detecting the difference Δt between the two times. The valve generator supplying the alternating potential to the quartz transmitting plate was modulated with a frequency, the period of vibration of which was calculated from the equation—

$$\tau = \frac{1}{f} = \frac{2l}{c}$$

It is necessary that the frequency of vibration of the generator feeding the quartz should be much less than the frequency f . The modulation should be designed in such a way that the vibrations exist only during the positive half-cycle of the modulation, and disappear during the negative half-cycle.

In order to avoid inductive effects of the generator on the receiver, the latter, consisting of a quartz detector and the amplifying system was supplied simultaneously with a potential at the modulator frequency applied to the grid of the last amplifying valve, the phases of the potential feeding the amplifier and the generator being 180° . Consequently, during the positive half-cycle of the modulation, high-frequency vibrations are generated in the transmitter while the receiver remains blocked, as during this time it is being supplied with the negative half-cycle of the modulation, whereas when the negative half-cycle of the modulation is supplied to the generator no vibrations arise, while

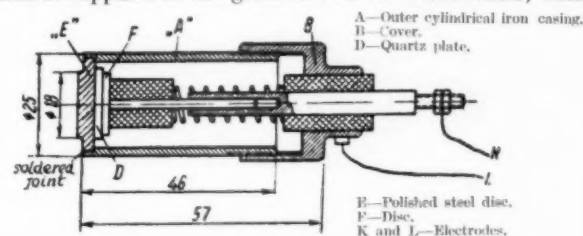


Fig. 5.—Ultrasonic generator.

at the same time the receiver comes into action, as it is supplied with the positive phase of the potential. In this way it is possible to get rid of the direct effect of the high-frequency generator on the amplifier, the latter remaining in action only during a time when the elastic vibrations act on the detector, as the ultrasonic vibrations will cover a distance l and act on the quartz detector only after $\frac{\tau}{2}$,

i.e., when the positive phase is being applied to the anode of the amplifying valve. If the metal is homogeneous, the maximum effect will be obtained in the receiver. If the metal contains a flaw, the vibrations passing through the metal will apparently be bent round the flaw and partly reflected from it, and the vibrations picked up on the other side will arrive with a certain lag, consequently the effect they will produce in the receiver will be less. For very thick parts to be examined, the modulation frequency should preferably be made equal to $f = \frac{c}{4l}$.

An alternative method is to use the echo-sounding principle—that is, to measure the time required for the vibrations to pass through the metal and back again. The plate of the transmitter will in this case also act as the detector. It is necessary to point out that in all these methods the decrement of the quartz plates should be as large as possible, and at the same time the modulation potentials applied to the generator and the receiver should be exactly 180° out of phase. For this purpose one can use a number of existing and well-known circuits developed in radio-technics.

The above methods will not, however, enable one to eliminate the undesirable phenomenon of multiple reflection of the ultrasonic vibrations from the boundaries of the part under investigation and their unfavourable effects. The phenomenon of multiple internal reflections is similar to the phenomenon of reverberation of ordinary sound in a closed space. The duration of these vibrations may

⁵ "Ultrasonic Method of Determining Internal Flaws in Metal Parts." S. Ya. Sokolov, *Zavodskaya Laboratoriya*, 1935, No. 12, pp. 1468-1473.

amount to several thousandths of a second, and it will be evident that vibrations of such duration may seriously distort the true state of affairs. In order to get rid of these effects, the high-frequency generator is again operated, only for a very short interval of time (of the order of 10^{-5} secs. for small parts). The receiver should at the same instant be made to function for approximately the same duration, or preferably for a somewhat shorter period, after which both the generator and receiver remain inactive for an appreciable time (about 0.01 secs.). The cycle is then repeated. During the period of 10^{-2} secs. the vibrations in the specimen will have had time to die away completely, so that during the second cycle the whole process will recommence. The receiver may either consist of a piezo-electric quartz plate and amplifier or of an optical arrangement based on the phenomenon of diffraction of light. The instants at which the generator and receiver function should not coincide. In any case, the receiver should be switched on at the instant the vibrations arrive at the point at which they are received, and should then be switched off. The switching off of the generator and receiver is effected by means of a rotating disc doing 50 to 80 r.p.s.

In the author's experiments, a 75 cm. diameter disc with slits was used to operate a photo-electric cell, the potential from which was amplified and then applied to the modulator. It is necessary to point out that the electrical constants of the circuits of the amplifier, and the decrements of the generator, and of the quartz plate should be chosen in such a way that the times of growth and decadence of the vibrations are as small as possible—in any case, smaller than the time of switching on the generator and the receiver.

Finally, another method may be mentioned. This consists of using a quartz transmitter set into vibration by means of the usual type of high-frequency generator, the frequency of which varies rapidly by 10–15% from its basic frequency. The frequency of the generator is varied by rapidly changing the capacity of the oscillating circuit, which may be easily done by using a variable condenser mounted on the spindle of a small electric motor. The vibrations modulated in this way are conveyed to the quartz vibrator, and the vibrations are received in the usual way by means of a quartz detector and amplifier. At the output end of the amplifier, a sound of a particular frequency will be heard in a telephone. If the ultrasonic vibrations have to take a longer path through the metal, the sound in the telephone will be lower in pitch, while if the path through the metal is shorter, the pitch will rise, and, finally, the sound will disappear altogether if the vibrations passing through the metal are stopped. The sound in the telephone is caused by the beat between the frequency of the generator at the instant of transmission and its frequency at the instant when the vibrations are received. This difference will depend on the distance travelled by the ultrasonic vibrations through the metal.

Careful screening of the generator, the detector, and of all connections is essential. Simple earthing of the screens was found to be quite insufficient; therefore the metal box containing the generator is placed into a second box with double walls of iron or brass. The first box is insulated from the second, which is earthed. The armoured cable which carries the leads to the transmitter is covered by a second sheath insulated from the first, this second sheath being connected to the second box. In addition, chokes are included into the leads from the mains to the generator.

Later work⁶ has shown, however, that the amount of screening necessary depends to a large extent on the output of the generator, and that a much simpler form of screening is generally adequate.

For detecting lack of penetration in welded steel plates, a special transmitting and receiving apparatus was developed. For lack of penetration covering 1 cm.² or more, a lower frequency of 4.5×10^6 was used. For smaller areas of about 0.25 cm.² higher frequencies were used.

The high-frequency generator was modulated with a frequency of 50 cycles per second, by the direct application of the a.c. mains. The output of the receiver was applied to a loudspeaker or cathode ray tube. A loud sound was given out by the loudspeaker when the welds were good, the sound dropping off or ceasing altogether if lack of penetration was encountered. In this way lack of penetration down to 0.1 cm.² could be detected.

Similar methods have been applied to the testing of bearings, bushings and hollow cylinders. For examining castings and forgings with unfinished surfaces and thicknesses of about 100 mm. frequencies not exceeding 1.5×10^6 were used, the parts being examined while immersed in a tank of transformer oil.

Tests on the application of the methods developed by Sokolov have been described by Otpushchennikov.⁶ The high-frequency generator circuit used is illustrated in Fig. 4 and the piezo-electric quartz ultrasonic generator in Fig. 5. The detector used was similar in construction to the generator. It was connected to a high-frequency receiver and through an amplifier stage to a loud speaker. The sound heard in the loud speaker when ultra-sonic vibrations were received was due to the anode voltage ripple which had not been smoothed out before being applied to the generator. A loud speaker was found to be suitable as a detecting instrument only for thicknesses of 8 to 10 cms. For thicknesses of 20 to 30 cms. a valve voltmeter with a measuring instrument having a sensitivity of about 10^{-7} amps. was used. As referred to above, it was found that when working with low power simple earthing of conductor sheaths and of the instrument screens was sufficient. With higher power outputs, the inductive effect of the high-frequency generator could be eliminated by detuning the second stage of the receiver. Any effect due to direct metallic contact between the emitter and detector can be eliminated by making the bottom "E" (Fig. 5) of the detector of glass or by interposing a layer of suitable insulating material. The method was used to detect longitudinal cracks in rail-heads.

In a more recent article,⁷ some interesting particulars generally referring to the design of ultrasonic equipment for the examination of metals have been given. In the more complicated form of high-frequency generator the frequency is crystal-controlled and for works' use a ferro-resonance type of supply voltage stabilising system is advisable. The frequency employed depends on the condition of the surface. For unfinished surfaces frequencies of about 1.5×10^3 kHz are sufficient, while for parts with smooth surfaces and for the purpose of detecting small defects, the frequency may be increased to 10^4 kHz. While increasing the frequency increases the sensitivity of the method and improves the directional property of the beam, it complicates the electrical equipment, making necessary the use of more efficient screening and the use of a superhet type of receiver. The scattering of the ultrasonic vibrations by the unevenness of the surface is also increased. A 20 to 50-watt generator is sufficiently powerful for the examination of medium size parts. The generator is usually modulated with a frequency of 50 Hz, an unrectified a.c. voltage being applied to the anodes of the valves for this purpose.

As far as the receiver is concerned it should be designed to make it incapable of receiving signals, the amplitude of which falls below a certain value, while its amplification for larger amplitudes should increase rapidly. This is necessary to render the receiver insensitive to scattered and reflected vibrations and ensure amplification of only the vibrations of the main ultrasonic beam. Blocking of the receiver for low amplitude is achieved by incorporating a diode detector to the anode, of which one can apply any desired negative voltage from a potentiometer.

A telephone, a loud speaker, a neon lamp, a voltmeter or a recording device may be used as indicators. A recording device is preferable for routine work. The parts to be

6 "Ultrasonic Method of Examining Metals," N. P. Otpushchennikov, *Zavodskaya Laboratoriya*, 1937, No. 8, pp. 999-1002.

7 "Determination of Defects in Metal Objects by the Ultrasonic Method," D. S. Shrayber, *Zavodskaya Laboratoriya*, 1939, No. 8, pp. 816-826.

examined are placed in an oil tank. After clamping the part in the oil tank, the ultrasonic generator and the detector are placed on either side of the part. The generator and receiver are then switched on. The former is tuned to give the maximum ultrasonic output which can be gauged from the motion of a layer of oil poured on the plate of the generator, while the receiver is tuned to give the maximum response of the indicating device. It is then necessary to see whether any reflected vibrations are reaching the detector. For this purpose a wooden board is placed between the generator and the detector. The latter should then indicate a complete absence of vibrations. If this is not the case, the receiver should be tuned in such a way as to render it insensitive to vibrations being received under those conditions.

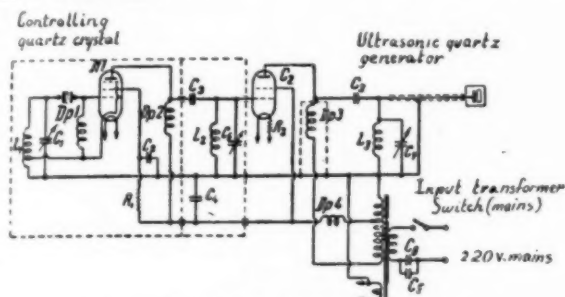


Fig. 6.—Circuit of defectoscope generator.

Finally, the receiver must be regulated to the sensitivity required to detect flaws of a given size. This is done by using specimens with standard flaws or wooden boards of suitable thickness. After the above preliminary adjustments have been made, the part to be tested is systematically "gone over," the location of any flaws detected being marked on its surface.

The author then goes on to describe two ultrasonic defectoscopes—one, the simpler one, for laboratory use and the other for works' use in the examination of forged duralumin propeller blades. In the second defectoscope the undesirable behaviour of the first type, which did not give very clear indications when the ultrasonic beam had been appreciably reduced in intensity on passing through the sound portion of the object, was corrected.

In the apparatus the blade is placed on rotatable supports in a tank filled with transformer oil. Rails are mounted on the edges of the tank, these rails carrying a sliding chassis on which is mounted the electrical equipment, the mechanism for altering the position of the beam, the visual indicator, the recording device, and the electric motor and drive mechanism which moves the whole chassis.

The circuit of the high-frequency generator is illustrated in Fig. 6. It is crystal-controlled, and the applied voltage is stabilised. The complicated shape of the parts to be examined gave rise not only to refraction effects, but also to interference between the direct and reflected ultrasonic beams with the formation of stationary waves. These effects tended to give rise to uncertain indications, the neon lamp visual indicator at certain points giving out a very unsteady light. Interference effects were compensated for by increasing the power output of the generator. In order to eliminate flickering of the neon lamp, the receiver (Fig. 7) incorporates a device which blocks its low-frequency side when the signals received are below a certain amplitude. This blocking is effected automatically by means of a special generator which forms a part of the receiving apparatus. The approximate amplitude characteristic is shown in Fig. 8. Signals, the amplitude of which is below a certain value, are not amplified at all. Above a certain amplitude the value of which can be varied, the receiver begins to function and amplifies signals of varying intensity to approximately the same output voltage. The neon lamp indicator, therefore, functions much more definitely either lighting up or remaining extinguished.

The recording device consists of two drums on which is wound a strip of light sensitive paper. As the drums rotate the strip unwinds from one and winds up on the other. In front of one of the drums is fixed a small flash-lamp bulb which is connected to Output II of the receiver. As the whole chassis moves along, the light sensitive paper unwinds and the light from the flash-lamp bulb traces a line on it. At the end of the propeller blade the movement of the chassis is automatically reversed, the bulb lifted up through a short vertical distance and the strip of light sensitive paper starts to unwind in the opposite direction. In this way one obtains a record consisting of a series of parallel lines which break off at points corresponding to defects in the blade. Such defects will therefore appear in the form of white spots in the diagram, these spots

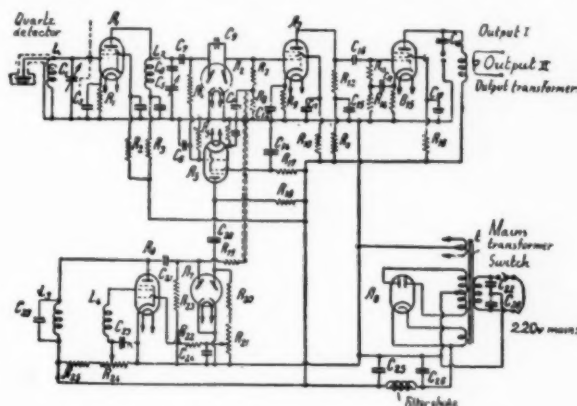


Fig. 7.—Circuit of receiver of defectoscope.

accurately reproducing the size, shape and position of the defects.

The ultrasonic method provides a means of detecting internal lamination, which is a characteristic defect in forged duralumin blades. From the above description taken from the latest article published on ultrasonic testing, it is evident that it has reached an advanced, though by no means final, stage of development.

In conclusion, it would appear to be useful to sum up the special features of the ultrasonic method as compared with radiographic examination. The outstanding merit of the ultrasonic method is undoubtedly its ability to detect defects which do not represent a sufficient change in "density" to enable their detection by X-rays. Thus,

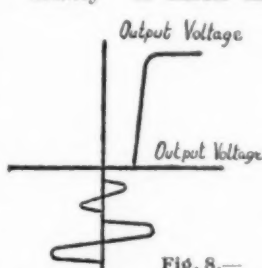


Fig. 8.—
Approximate amplifying
characteristic of receiver.

cracks or laminations situated in a plane at right angles to the beam can be detected with certainty. As far as large blowholes are concerned, the sensitivity of the two methods should be about the same. The second advantage of the ultrasonic technique is its ability to deal with cross-sections of metal which could not be penetrated by X-rays or even γ -rays. In this connection the possibility of using

ultrasonics for the examination of large steel ingots comes to mind. On the other hand, the ultrasonic method can only be used for examining one part at a time and probably is also somewhat slower than radiography. Nevertheless, the semi-automatic functioning of the ultrasonic apparatus like the one described above should constitute a definite advantage from the point of view of its routine use for the examination of standard production parts.

It is hoped that the present article will succeed in inducing the interest which the ultrasonic method of non-destructive testing undoubtedly deserves.

The Electrolytic Polishing of Stainless Steels

By H. H. Uhlig

The use of glycerine-phosphoric acid mixtures for electrolytically polishing 18-8 stainless steel is described in a paper by the author, presented at the recent Ottawa meeting of the Electrochemical Society. Optimum conditions to produce polish were determined with the aid of a photoelectric spectrophotometer. It is shown that maximum polish is obtained with an electrolyte consisting of approximately 42% H_3PO_4 , 47% glycerine and 11% water by weight, used at 100° C. or higher, and anode c.d. of at least 0.1 amp./sq. in. (1.5 amp./dm.²). Many other steels can also be polished in these organic solution-phosphoric acid electrolytes.

A HIGH degree of reflectivity is desirable for some applications of stainless steel. This is usually obtained by tedious and expensive processes involving multiple operations of mechanical buffing. Bright pickles have been proposed to obtain brighter surfaces of steels, but the degree of polish which results, although suitable for many purposes, does not equal a mirror finish. Recently there has been a definite trend in the industry towards electrolytic polishing. The steel is made anode in a suitable bath and in relatively short time, by anodic solution of high points on the steel surface, a remarkably successful polish results which in many ways is comparable with finishes produced by buffing. The time required to produce a polish is dependent upon the nature of the original surface, but, in general, the electrolytic process is considerably less time-consuming and less expensive than the equivalent mechanical procedure.

Phosphoric Acid Organic Solutions

In the course of an investigation of electrolytic polishing of stainless steels, it was found that, when operated above room temperature certain organic substances added to orthophosphoric acid provided an electrolyte which offered several advantages. The reflectivity of stainless steel specimens polished in these solutions was very high (using low c.d.s.), metal loss was low, and pitting, often encountered in other electrolytes, was not found. The use of low current densities is of special practical significance because the 18/8 alloy is a relatively poor conductor of electricity and tends to overheat locally on passage of large currents. Possible lower currents, therefore, to produce polishing, make feasible the treatment of large-area anodes.

Organic additions to phosphoric acid which were found to produce best results included glycerine, carbitol (diethylene glycol monoethyl ether), methyl cellosolve (ethylene glycol monomethyl ether), ethylene glycol, and acetic acid. As a category, substances of high boiling point containing one or more hydroxyl groups which are soluble in phosphoric acid were outstanding in polishing efficiency. Addition of primary alcohols like ethyl or methyl alcohol also produced reasonably good electrolytes, but volatility was too great and degree of polish obtained not equal to that of the electrolytes containing additions boiling at higher temperatures.

Specific Conditions for Glycerine-Phosphoric Acid Electrolyte

Optimum conditions for electrolytically polishing 18/8 stainless steel were studied for glycerine-phosphoric acid-water mixtures. Degree of polish was conveniently measured by using a photoelectric spectrophotometer designed by Professor Hardy. The degree of polish is reported as "Per cent. specular reflectance." Specular reflectance is the difference between total reflectance and scattered reflectance, hence a measure of the mirror finish. All test specimens were prepared from an 18/8 stainless steel sheet containing 18.97% chromium, 9.72% nickel,

and 0.13% carbon, "cold rolled 2 B," commercial finish, No. 26 gauge (0.47 mm. thick), and were not further surface treated except cleaning in distilled benzene. The specimens measured 2½ in. by 1 in. (63.5 × 25.4 mm.), and were immersed so that exactly 1 sq. in. (6.45 cm.²) of anode per side was in contact with the solution. Two cathodes of comparable size and immersed area, also of 18/8 steel, faced the anode on either side.

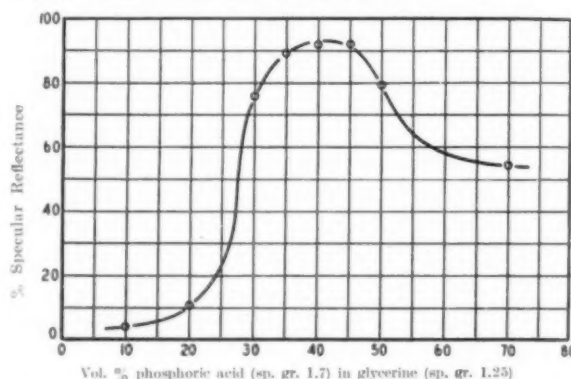


Fig. 1.—Effect of variation of phosphoric acid on reflectance of electrolytically-polished 18/8 stainless steel.

It was found that the ultimate degree of electrolytic polish varied somewhat with the steel. This, apparently, was due not to small variations in major composition, but to differences in inclusions or homogeneity of the alloy. A relatively clean steel, just as is the case in mechanical polishing, was found to produce best results.

Results.—The effect of 85% phosphoric acid (sp. gr. 1.7) in 96% glycerine (sp. gr. 1.25) at 100° C., and anode current density of 0.5 amp./sq. in. (7.78 amp./dm.²) on degree of polish, is shown in Fig. 1. Time of anode treatment was 15 mins. Approximately 93% specular resistance, the optimum, occurs between 35% and 45% phosphoric acid by volume. By way of comparison, the original cold-rolled finish measured 22.7% specular reflectance.

A 40 vol. % phosphoric acid solution corresponds to 44.4 wt. % phosphoric acid in glycerine on an anhydrous basis. Maintaining the phosphoric acid on the anhydrous basis of 44.4 wt. %, the effect of water addition is shown in Fig. 2. A c.d. of 0.5 amp./sq. in. (7.78 amp./dm.²) 15-min. treatment, and temperature of 100° C. were maintained as before. The optimum water concentration in glycerine-phosphoric acid is found to occur at 10–11% by weight.

The effect of temperature is shown in Fig. 3, using a 40 vol. % H_3PO_4 (sp. gr. 1.70) in glycerine (sp. gr. 1.25) and c.d. of 0.5 amp./sq. in. (7.78 amp./dm.²). The higher the temperature, the better is the polish. It was first thought by visual inspection that the addition of 3% boric acid to the electrolyte improved the results, but additional data including boric acid in the electrolyte and plotted in Fig. 3 prove that there is no effect.

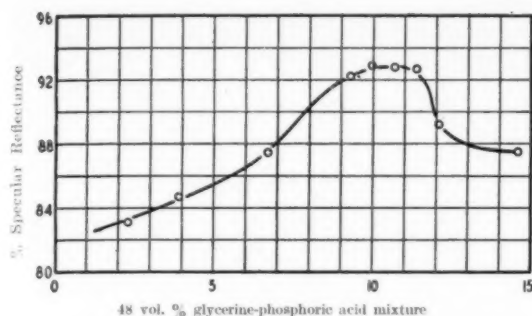


Fig. 2.—Effect of water additions to 40 vol. % H_3PO_4 in glycerine on reflectance of 18/8 stainless steel.

Current density is not critical above 0.1 amp./sq. in. (1.5 amp./dm.²) as data plotted in Fig. 4 show. Here 40 vol. % H_3PO_4 (sp. gr. 1.70) in glycerine (sp. gr. 1.25) was used at 100° C. Time of electrolysis at 0.5 amp./sq. in. (7.75 amp./dm.²) was 15 mins., and time for polishing specimens at differing current densities was varied so that the total amount of electricity (450 coulombs) which passed for each experiment was always the same. The amount of anodic metal removed, as determined by micrometer measurements, was larger at low current densities. This is shown in Table I. All metal removed was by anodic solution. The weight losses by pickling action independent of current in the same periods of immersion were found negligible.

TABLE I.

EFFECT OF CURRENT DENSITY ON METAL REMOVED IN ELECTROLYTIC POLISHING OF 18/8.

Current Density.		Time of Polishing.	Metal Removed.	
0.05 amp./sq. in.	0.78 amp./dm. ²	150 min.	0.0005 in.	12.7μ
0.1	1.6	75	0.0004	10.2
0.4	6.2	18.8	0.0004	10.2
0.5	7.8	15	0.0003	7.6
1.0	15.6	7.5	0.0003	7.6
2.0	31.1	3.75	0.00025	6.4

Starting with a cold-rolled surface, the amount of metal removed electrolytically to produce a high degree of polish is small. Because of oxygen evolution at the anode coincident with removal of metal, the current efficiency at 0.5 amp./sq. in. (7.78 amp./dm.²) is approximately 30%, the efficiency falling off at higher current densities. Reflectivity is best at low c.d.s. (0.1 to 0.5 amp./sq. in.) (1.5-7.8 amp./dm.²), but falls off sharply below 0.1 amp./sq. in. (1.5 amp./dm.²) despite the fact that the same order of metal thickness is removed. A possible reason for this behaviour is discussed later.

Polishing Applied to Other Metals

In addition to austenitic 18/8, which can be polished to a high degree, using the phosphoric acid-organic mixtures, other metals are electrolytically polished in the same solutions. In some instances the critical compositions or

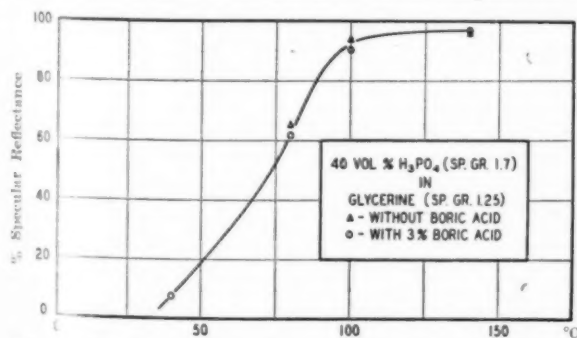


Fig. 3.—Effect of temperature on reflectance in electrolytic polishing of 18/8 stainless steel.

temperatures must be altered. In polishing chromium steels or mild steels it was found that temperatures lower than 100° C. are preferable. In general, nickel, copper, chromium steels, 18/8 containing molybdenum, and mild steel could be polished using the 40 vol. % phosphoric acid-glycerine mixture at temperatures ranging from 50° to 150° C.

Steel and iron are more difficult to polish than 18/8 stainless steel, because, among other reasons, varying carbon content alter the conditions for producing best results. It was found that an excellent polish could be produced on mild steel surfaces using a 50 vol. % carbitol-phosphoric acid (sp. gr. 1.70) mixture at a temperature of 50°-80° C., and c.d. of 0.5-1.0 amp./sq. in. (7.78-15.5 amp./dm.²) for a period of 15 min. or longer.

Theory of Electrolytic Polishing

Electrolytic polishing of metals is apparently accomplished by preferable anodic solution of high points on the surface of the metal. Anodic corrosion products form a viscous, poorly conducting film of metal phosphates which adhere to the "valleys" but expose the "hills" to the electrolytic solution. Eventually the metal surface is levelled to a microscopic plane showing under certain conditions macroscopic undulations. As a number of workers have shown, the microscopic surface corresponds to a degree of polish equal to or better than that obtainable on a metallographic polishing wheel.

Phosphates are in the category of ions essential to the polishing electrolyte, apparently because metal phosphates can form the viscous film which protects from anodic attack the metal-forming recesses and cavities of the surface. These ions migrating to the anode surface can be pictured as forming concentrated metal phosphates in reaction with metal undergoing electrolytic solution. The viscous metal phosphates limit the current reaching the underlying metal, which they blanket, and only slowly diffuse into the main body of the electrolyte. During the slow diffusion, metal protuberances exposed to the electrolytic action are more rapidly attacked. Perchlorates, fluorides and nitrates were also found in the category of acid radicals which form soluble metal complexes, and compounds are necessary apparently at the anode surface to effect polishing action.

Sulphates, on the other hand, were not as successful as phosphates for electrolytes to polish stainless steels. One reason is that metal sulphates, of which ferrous sulphate is an example, have limited solubility in the more concentrated sulphuric acid solutions, and there is no tendency for a concentrated liquid phase to form which can protect underlying metal from attack. Some evidence has been accumulated to illustrate the mechanism, whereby addition of organic substances to phosphoric acid improves polishing. The decomposition potentials of glycerine- H_3PO_4 mixtures at 100° C. were found to be no different from that of phosphoric acid alone at the same temperature, so that the electrode reactions appear identical. The current-voltage data which show this for 18/8 electrodes in phosphoric acid and the 40 vol. % phosphoric acid in glycerine mixture are plotted in Fig. 5. The decomposition potential for each solution is at 1.3 v. The conductivity of the glycerine mixture, however, is lower, which fact probably has some bearing on its effect of improving polishing. The dip in the current-voltage curve occurring at 2.3 v. and anode c.d. of approximately 0.1 amp./sq. in. (1.6 amp./dm.²) corresponds to the critical values for appearance of electrolytic polishing. Below these critical values, metal is anodically dissolved, but leaves the anode surface etched with low reflectance, whereas above 0.1 amp./sq. in. polishing occurs. This is in accordance with data presented in Fig. 4 showing the relation between polishing and current density. It seems fairly evident that the anode film of metal phosphates can maintain itself at or above the critical current density, but not below. This it probably does by virtue of phosphate ion migration towards the anode which builds the film as opposed to diffusion into the

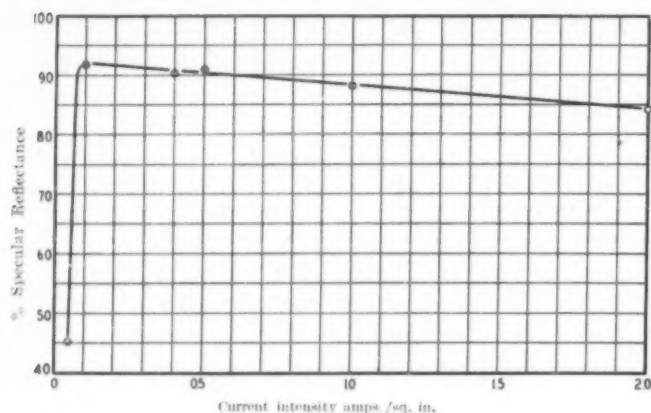


Fig. 4.—Effect of current density on reflectance of electrolytically-polished 18/8 stainless steel in H_3PO_4 -glycerine mixture.

electrolyte. Below the critical current density diffusion processes appear to exceed rate of formation of the phosphate film, with consequent disruption of polishing.

The molal percentage (Fig. 1) of phosphoric acid in glycerine to produce optimum polishing (approximately 43 vol. %) is calculated approximately equal to that of glycerine (28.0 and 33.6 mol % respectively). This leads to the possibility that a complex ion is formed originating from glycerine phosphates, $C_3H_5(OH)_2H_2PO_4$, which would be expected from its structure and size to conduct less readily than phosphoric acid. This is in accordance with data of Fig. 5, which indicate diminished conductivity of the glycerine solution. Metal derivatives of this complex may, in addition, form a complex phosphate film, giving better protection to the surface than phosphate alone. The water content and temperature of the glycerine-phosphoric acid electrolyte serve, presumably, on the basis of this mechanism to alter electrical conductivity of both elec-

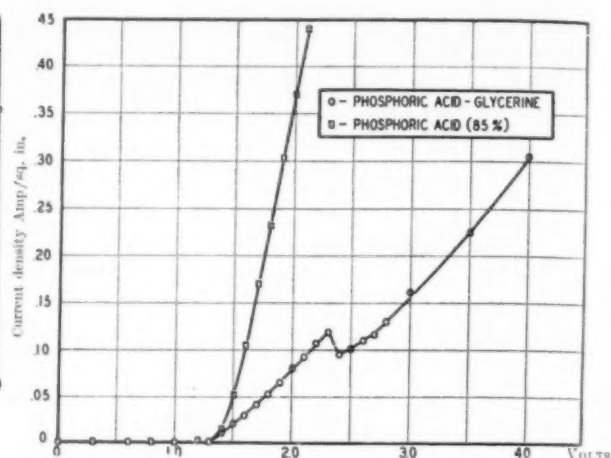


Fig. 5.—Anode current density-voltage data for 1 sq. in. 18/8 electrodes separated $1\frac{1}{2}$ in. in polishing electrolytes at $100^\circ C$.

trolyte and anode film, so that conditions for polishing are optimum. The optimum water content occurs at a mol percentage approximately equal to that of glycerine and phosphoric acid.

An important function of glycerine, or a similar organic addition, is to prevent pickling action of the anode by acid independent of anodic solution. If pickling occurs, due to local electrolytic action on the surface, etching rather than polishing results. It was found in proof of this premise that concentrated phosphoric acid attacks 18/8 stainless steel at elevated temperatures, but that the addition of glycerine in equal molal concentration inhibits attack and hence preserves the polished surface. It is this factor of etching by localised attack which serves to increase the difficulty of electrolytically polishing steel and iron as compared with stainless steels.

Chairman and Deputy Chairman of Hadfields Limited

At a recent meeting of the board of directors of Hadfields, Ltd., Mr. P. B. Brown, J.P., M.Inst.C.E., was appointed chairman in succession to the late Sir R. A. Hadfield, Bart., and Major A. B. H. Clerke, C.B.E., later R.A., was appointed to succeed Mr. P. B. Brown as deputy chairman.

Mr. P. B. Brown joined the company in the year of its formation, 1888, was appointed a director in 1909, a managing director in 1917, became deputy chairman in 1930. Major Clerke joined the company in 1911, was elected a director in 1913, and a managing director in 1917.

Modernising Old Steel Plants in the U.S.S.R.

THE iron and steel industry in the south of the Soviet Union is embarking on an extensive programme for the modernisation of old steel plants, with a view to bringing them into line with modern practice in the industry. Twelve large open-hearth furnaces in southern plants are to be made completely automatic, while 38 will be partially equipped with automatic apparatus.

In connection with this programme, the southern iron and steel industry has received from Soviet engineers numerous devices for the automatic operation of open-hearth furnaces. These devices cover the following processes: Fuel feeding to the furnace, regulated by the heat of the furnace top; regulation of the proportion of blast-furnace and coke-oven gas and of the fuel and air; regulation of the pressure in the furnace.

The Constitution of the Lead-rich Alloys of Lead, Antimony and Cadmium

THE service life of lead pipes and cable sheaths has been greatly extended by the introduction of alloying additions to lead. One commonly used alloy contains 0.25% cadmium and 0.5% antimony; it is one of the ternary lead alloys developed by the British Non-Ferrous Metals Research Association, the manufacture and use of which are covered by British Patent 272,320. Investigators have shown that age-hardening has an important part in this alloy, and this investigation* by Rollason and Hysel on the determination of the solid-solubility limits in the lead-rich antimony-cadmium-lead alloys has both theoretical and practical value.

Using thermal, electrical-resistivity and microscopical methods, the constitution of alloys of lead with antimony and cadmium has been investigated up to about 15% of antimony and 20% of cadmium. The results are shown in vertical and horizontal sections of the constitutional model. The liquidus consists of four areas, representing the separation of the α , β , γ and δ phases, respectively. Lead and CdSb form a pseudo-binary system with a eutectic at $275^\circ C$. containing cadmium 4.32 and antimony 4.69%. Two ternary eutectics occur: (i) at antimony 11.3, cadmium 1.3%, and (ii) at cadmium 18.5 and antimony 2.5%. The solid solubility of cadmium and antimony in lead has been determined at various temperatures. The solid solubility on the pseudo-binary section at $275^\circ C$. is 2.5% CdSb, while at $25^\circ C$. it is less than 0.3% CdSb. The addition of cadmium greatly reduces the solubility of antimony in lead, but antimony has little effect on the solubility of cadmium in lead.

*N. C. Rollason and V. B. Hysel, *Jour. Inst. of Metals*, 1940, **66**, 10, pp. 249-53.

Resistance of Aluminium-Magnesium Alloys to Attack by Sodium Carbonate Solutions

The rates of attack of a series of high-purity aluminium-magnesium alloys and also of several commercial aluminium alloys by sodium carbonate solutions at 31° C. have been studied, and it is shown that alloys containing substantially more than 2 to 3% magnesium are much more resistant to attack by 1 to 10% solutions than are aluminium-base alloys of lower magnesium content.

ALUMINIUM-BASE alloys containing up to 10% magnesium have come into extensive use during the past decade. These alloys combine relatively high physical properties with outstanding stability to most neutral salt solutions. A number of investigators have stated that these alloys are particularly resistant to alkaline solutions; a point of considerable interest, since alkaline cleaning solutions are often used in contact with aluminium equipment. Attack by such alkaline solutions can be largely or entirely prevented by the addition of inhibitors; in some cases, however, it is either undesirable or impossible to make such additions, thus alloys possessing a higher resistance to alkaline solutions are sometimes advantageous.

Since magnesium itself is quite resistant to alkaline solutions, it might be expected that additions of magnesium to aluminium would form alloys with a higher resistance to such solutions than does pure aluminium; tests in sodium carbonate solutions, however, have shown that small additions of magnesium, of 2 to 3%, result in a decrease in resistance to corrosion and that more than about 4 to 5% magnesium is required to produce alloys possessing a substantially greater resistance to attack than does pure aluminium. This conclusion is reached by Mears and Benson* as a result of a study of the rates of attack on a series of high-purity aluminium-magnesium alloys, and also of several commercial aluminium alloys by sodium carbonate solutions at 31° C.

TABLE I.
NOMINAL PERCENTAGE COMPOSITION OF COMMERCIAL AND EXPERIMENTAL ALLOYS.

Alloy.	Si.	Mn.	Mg.*	Cr.
28-1/2H†	—	—	0.0	—
38-1/2H	—	1.2	0.0	—
538-W	0.7	1.3	1.21	0.25
528-1/2H	—	—	2.31	0.25
Exptl. 2	—	—	3.48	0.25
Exptl. 1	0.25	—	4.09	—
568-1/2H	—	—	5.22	—
No. 229 casting	—	—	10.06	—

* Determined by analysis.

† Commercially pure aluminium, 99% Al minimum.

The main series of tests was made on alloys containing 0.00, 0.46, 1.01, 1.54, 2.05, 3.08, 3.99, 5.17, 6.10, 7.25, 8.77, and 10.13% magnesium; the aluminium and magnesium used in making the alloys having a purity of 99.984 and 99.98% respectively. After casting, the ingots of the various alloys were given a homogeneous anneal, hot-rolled to 0.64 cm. thickness, annealed, and cold-rolled to 0.064 cm. thickness. Specimens 1.9 × 6.4 cm. in size were cut from the sheet. Some tests were also made with standard commercial alloys, the compositions of which are given in Table I. The specimens of these alloys were 2.5 × 10 cm. in size and generally 0.16 cm. thick, the exception being the alloy in cast form the specimens of which were 0.63 cm. thick.

The test results are summarised in Figs. 1, 2 and 3. Fig. 1 shows that the rate of attack varies greatly with all alloys as the concentration of the sodium carbonate solution

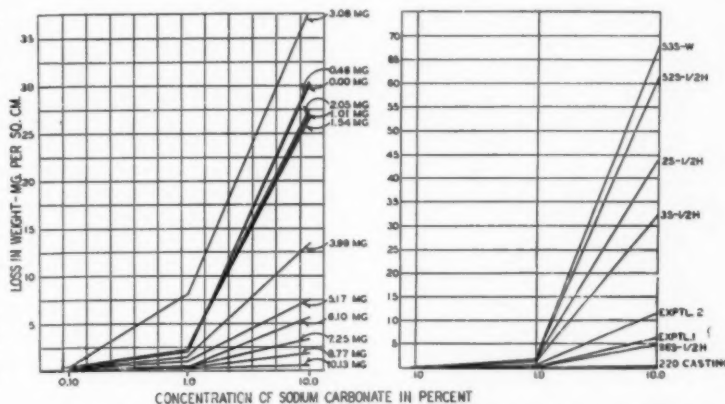


Fig. 1.—Ratio of attack on aluminium-magnesium alloy specimens and on commercial and experimental aluminium alloy specimens, exposed one week in sodium carbonate solutions at 31° C.

is altered. Attack does not become appreciable in any case until a concentration of 0.10% is attained. For the group of special alloys the type of attack in the more concentrated solutions ranged from a moderate to a very uniform etching on all specimens except those containing no magnesium. On these latter specimens (in the 10% sodium carbonate solution), severe special attack had developed adjacent to the edges and at isolated spots elsewhere on the surface. At some of these latter areas actual perforation of the specimens had occurred. In the more dilute solutions (0.001, 0.01, and 0.1%) attack was very uniform in all cases, and often resulted in the formation of a dull brown or black film.

Fig. 2 shows the relation between loss in weight and magnesium content of the specimens. The alloy containing 3.08% magnesium loses considerably more weight upon exposure to either the 1.0 or 10.0% sodium carbonate solutions than do any of the other alloys of the aluminium-magnesium series. Alloys containing more than 3% magnesium are less and less appreciably attacked in these solutions as the magnesium content increases. The alloy containing 10% magnesium only loses $\frac{1}{36}$ as much as does pure aluminium in the 10% sodium carbonate solution. This is a substantial decrease in the rate of attack.

The losses in weight of the various commercial alloys are also given in Fig. 2. Again, alloys which contain over 3% magnesium are considerably more resistant to the action of sodium carbonate solutions than is pure aluminium.

The relation between duration of exposure and rate of attack in the 10% sodium carbonate solution is shown in Fig. 3. After the initial period of 5 or 6 hours the rate of attack becomes practically constant up to the longest periods examined.

In general, these results confirm those from earlier tests in indicating that the addition of substantial amounts of magnesium markedly decreases the susceptibility of aluminium to attack by alkaline solutions; none of the previous workers, however, mentioned the occurrence of the sharp peak in the curve. For this reason additional tests were made to study this more closely. A new group of alloys was prepared, using aluminium and magnesium,

* B. B. Mears and L. J. Benson, *Ind. Eng. Chem.*, 32, No. 10, 1,343-7 (1940).

which differed in composition from the earlier materials. (The aluminium contained 0.003% silicon, 0.004% iron, 0.011% copper, and 0.002% magnesium; and the magnesium approximately 0.010% each of copper, iron and nickel with only spectrographic traces of manganese, sodium, silicon, chromium, and calcium.) The ingots of these alloys were given a homogenising anneal, hot-rolled to 0.63 cm., then annealed and cold-rolled to 0.063 cm., usually with an intermediate anneal. A portion of this cold-rolled material was annealed at 343° C. for 2 hours. Three specimens of each alloy in each temper were exposed to the 10% sodium carbonate solution under the conditions described above. It was found in these cases also that maxima were obtained (Table II). However, the position of the new maxima differed from that previously obtained; it occurred at 1.90% magnesium for the cold-rolled material and at 2.55% for the annealed material, instead of at 3.08%.

The explanations of these maxima were not clear. However, they might have been associated with the solubility limit of magnesium in aluminium. At 200° C. about 3% of magnesium is soluble in aluminium at equilibrium conditions, but at room temperature the solubility is probably considerably lower at equilibrium conditions.

Microscopic examination was made of all the specimens which had been exposed to the 10% sodium carbonate solution. In the case of the first series of aluminium-magnesium alloys, some of the aluminium-magnesium

content. This showed a slight amount of precipitation at the grain boundaries. The pure aluminium specimens from this series of material, whether hard-rolled or annealed, also showed irregular attack, but attack of all of the other specimens was nearly uniform etching.

A possible electro-chemical explanation for this maximum

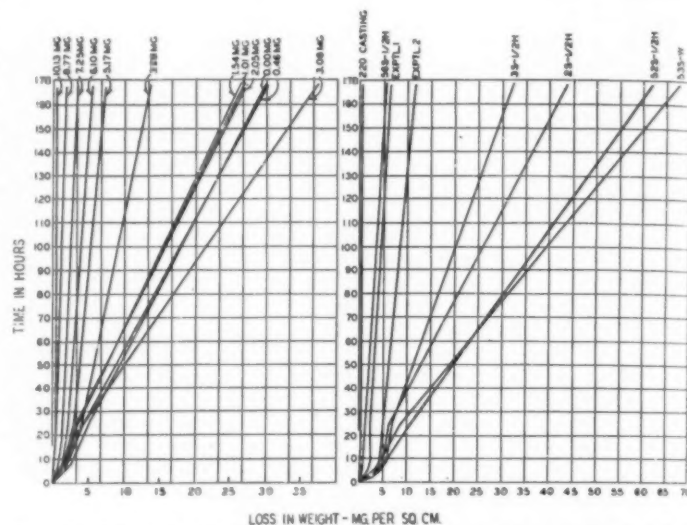


Fig. 3.—Effect of duration of exposure on rates of attack of aluminium-magnesium alloys and of commercial and experimental alloys by 10% sodium carbonate solutions at 31° C.

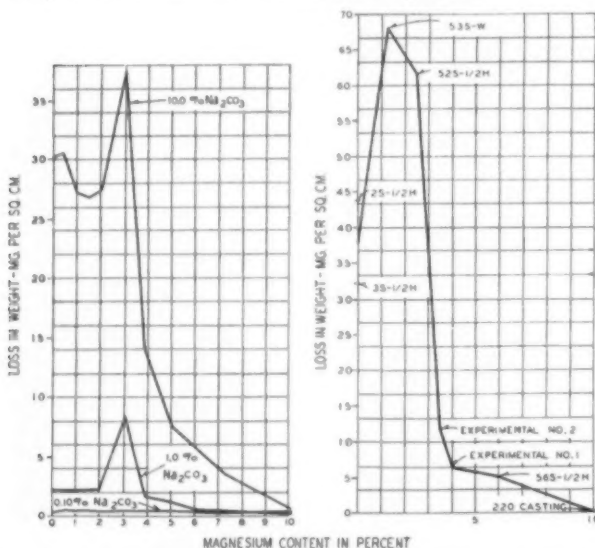


Fig. 2.—Effect of change in magnesium content on rates of attack of aluminium-magnesium alloys and of commercial and experimental alloys exposed one week in 10% sodium carbonate solution at 31° C.

constituent could be detected in the alloy containing 2.05% magnesium, but not in the alloys of lower magnesium content. Alloys of higher magnesium content showed increasing amounts of precipitate. In all cases except on the pure aluminium specimen the type of attack was nearly uniform etching. There was no evidence of special grain boundary attack in any of the specimens examined. The attack on the pure aluminium specimen was very irregular.

In the second series of aluminium-magnesium alloy specimens, a slight amount of precipitate was detected in the cold-rolled specimen containing 1.90% magnesium. Precipitation was more pronounced in the cold-rolled specimens of higher magnesium content. No precipitate was noted in any of the annealed specimens from this second series except the one of highest (4.03%) magnesium

was investigated, but was found to be inconsistent with solution potential measurements. The most likely explanation of the observed results appears to be one based on film formation, that differences in the continuity of the film of

TABLE II.
RESULTS OF ONE-WEEK EXPOSURE OF THE SECOND SERIES OF SPECIAL ALUMINIUM-MAGNESIUM ALLOYS* TO 10% SODIUM CARBONATE SOLUTION AT 31° C.

Al.	Alloy.	Loss, †	Mg. ‡	Loss, †	H Temper.
%	%	O Temper.	%	Mg. ‡	
99-98	—	17.8250	..	29.5716	
98-08	1.90	20.6532	..	37.5619	
97-43	2.55	23.6218	..	14.7353	
96-95	3.03	10.0886	..	13.6629	
96-42	3.56	10.2097	..	12.3386	
95-95	4.03	8.4298	..	10.6188	

* Size of specimens, 0.0061 × 1.9 × 6.34 cm.; approximately 5 cm. length immersed.

† 1 mg. per sq. cm. per week equals about 0.0076 in. average penetration per year.

corrosion products, which forms on the specimens, is responsible for the changes in rate of attack with changes in magnesium content. The effect of agitation of the sodium carbonate solutions with supersonic vibrations on specimens was also studied, and it was found that the agitation definitely stimulated the corrosive action of these solutions, probably by facilitating removal of hydrogen bubbles from the surfaces of the specimens.

Packing, Transport and Storage of Aluminium Alloys

A COMPREHENSIVE discussion on the means adopted to protect aluminium-base alloys during transport and storage is given in the September issue of "Aluminium Technique," published by Aluminium Union Limited. Aluminium alloys, particularly in the finished and semi-finished forms, are not unique in requiring for their safe keeping some measure of protection during storage and the observance of certain precautions during transport; other non-ferrous alloys also require to be suitably protected as a precaution against alteration subsequent upon superficial chemical attack by atmospheric moisture and other agents which may be encountered while the material is in stock, and against mechanical damage during transport. The methods adopted for the various forms in which aluminium-base alloys are transported and stored are of considerable interest.

Iron and Steel Institute

Annual Autumn Meeting held at Sheffield

The Autumn Meeting of the Iron and Steel Institute was held at Sheffield on November 12, and by arrangement with the Presidents and Councils of the Sheffield Society of Engineers and Metallurgists and the Sheffield Metallurgical Association a joint meeting of these Societies was held at which a number of technical papers were presented, brief reference to which is made in the following notes.

IT is noteworthy that under the stress of war conditions 275 members and friends should attend the annual autumn meeting of the Iron and Steel Institute, and the President, Mr. John Craig, C.B.E., expressed appreciation of the chairman of Committee of Arrangements, Dr. W. H. Hatfield, F.R.S., without whose help this would not have been attained. The initial function was a luncheon at which the Deputy Lord Mayor, in a few appropriate words, welcomed the various societies represented, and proposed the toast of the Iron and Steel Institute. In reply, the President referred to the City of Sheffield and to the importance placed upon the iron and steel industry in wartime, but he emphasised that its importance in times of peace is no less.

At the business meeting subsequently held, the President made feeling reference to the loss the Institute had suffered by the death of Sir Harold Carpenter and of Sir Robert A. Hadfield; he eulogised their work in the advancement of metallurgy, and mentioned that each had been president of the Iron and Steel Institute.

On the conclusion of official business several papers were presented for discussion. Considerable interest was shown in the work reported by B. Yaneske* on the manufacture of steel by the Perrin process. This paper was introduced by Dr. T. Swinden; it deals with the application of the Perrin process for the manufacture of low-carbon steels direct from blast-furnace iron containing 0.28-0.40% of phosphorus, after blowing it in an acid Bessemer converter, thus eliminating the basic open-hearth for finishing the blown metal. The essential features of the process are the basic oxidising slag and the height at which the blown metal is poured into it to ensure intimate contact between metal and slag to effect rapid dephosphorisation.

Preliminary experiments carried out at the steel works of the Société d'Electro-Chimie, d'Electro-Metallurgie et des Acieries Electriques d'Ugine, France, were only partly successful, but Mr. Ghandy, General Manager of the Tata Iron and Steel Co., Ltd., Jamshedpur, India, and Mr. Yaneske considered them sufficiently encouraging to justify the conducting of further experiments at the Tata Works in India. The result was that an exhaustive series of experiments were carried out at the Tata duplex plant. In all one hundred experiments were conducted, of which particulars of a selection are contained in the paper. In these experiments more than 3,000 tons of ingots were produced by the slag-dephosphorising direct process, with an average yield of 90.35% of ingots from blast-furnace iron plus alloy additions; and as the ingots were rolled into various products mostly with satisfactory mill yields, it was considered that the experimental stage had been passed and sufficient information obtained to ensure that the Perrin process could be operated on a commercial scale in a new plant specially designed for the process.

A brief description of the two South African blast-furnace plants—the Pretoria plant of the South African Iron and Steel Industrial Corporation, Ltd., and the Newcastle plant of its associated company, African Metals Corporation, Ltd.—was presented in a paper by R. R. F. Walton,† dealing with the practical side of blast-furnace management,

with special reference to South African conditions. Details of the furnace lines are given, and the raw materials used are discussed. Particular attention is directed to the handling of the furnace. The method of blowing-in with the usual charge and the results obtained are followed by notes on the necessity of regularity of the burden, charging and blast volume. The paper ends with a section on the South African personnel and unusual weather conditions.

The development of a method of automatic accelerated spray testing is described in a paper‡ presented by Dr. T. Swinden and W. W. Stevenson, in which the specimens on an endless belt, complete a cycle of treatment, consisting of spraying, followed by drying in air and in a warm chamber. The cycle is completed in 7 mins., and the specimens are subjected to 60 cycles per day. A standardised douching with water is given at the commencement of the second and subsequent days, and the daily spraying and drying treatment is carried on for 20 days. Comparative results of long-period field tests and spray tests are given for 14 irons and steels of the low-alloy constructional type.

At a subsequent session a controversial subject was raised in a paper by Dr. W. H. Hatfield and G. W. Giles, which deals with the quantitative evaluation of non-metallic inclusions in steel. The growing need for consistency in performance requires that steel should be as free as possible from non-metallic impurities and various methods have been adopted to indicate the quality of steel from the point of view of non-metallic inclusions. As will be gathered from the paper, reproduced elsewhere in this issue, the authors are of the opinion that present methods of quantitative estimation of the degree to which steels are contaminated by non-metallic inclusions are impracticable.

Another paper, presented by Dr. C. A. Edwards, F.R.S., D. L. Phillips, and H. N. Jones, gave the results of an investigation on the influence of carbon, aluminium, copper, nickel, molybdenum, manganese, chromium, vanadium, niobium, and titanium upon the strain-hardening properties of low-carbon steels. This paper was referred to at some length in the last issue of this journal. The authors found that the effect of the elements studied enable them to be placed in two main groups: those which show little or no tendency to combine with the carbon present in steel—aluminium, copper and nickel—and those which show definite tendencies to form carbides, such as molybdenum, manganese, chromium, vanadium, niobium, and titanium. The former increase and the latter diminish the extent of strain-age-hardening of low-carbon steels. They also found that as the capacity for strain-age-hardening is diminished by increasing quantities of specially added elements, the intensity of the yield-point diminishes, and no yield-point is revealed on a stress-strain diagram when sufficient alloying element is present to prevent strain-age-hardening.

A third paper, presented for discussion at this session by Dr. H. Lipson and N. J. Petch, concerns the crystal structure of cementite. The authors point out that previous workers have located the iron atoms accurately, but have failed to detect the carbon atoms. By direct calculation of the electron density in two different planes in the unit cell, using accurately measured intensities of X-ray reflection, it is claimed that the positions of the carbon atoms have now been found.

* See September METALLURGIA, p. 154.

† See July METALLURGIA, p. 81.

‡ See September METALLURGIA, p. 149.

Non-Metallic Inclusions in Steel

Quantitative Evaluation—Part I

By W. H. Hatfield, D.Met., F.R.S., and G. W. Giles, B.Sc.
(Brown-Firth Research Laboratories, Sheffield.)

The authors have sought to evaluate the different factors influencing methods of inclusion counting. Experimental evidence is given which indicates the importance of the magnification selected for observation purposes. It is shown that the comparison charts at present extant have not the quantitative value which has hitherto been attributed to them; and that the conditions of polishing influence the inclusion count. The view is expressed that present methods of quantitative estimation of the degree to which steels are contaminated by non-metallic inclusions are impracticable. This is Paper No. 3/1940 of the Heterogeneity of Steel Ingot Committee submitted by the Inclusions Sub-Committee for presentation at the Autumn General Meeting of the Iron and Steel Institute. It is given here in a slightly abridged form.

IT has always been an axiom that for consistency in performance steel should be as free as possible from non-metallic matter arising from whatever cause. This view has been accentuated of late years, owing to the increasingly high complex stresses which have to be resisted, as, for instance, in some of the modern aero-engine parts. That the tensile strength and the capacity for developing plastic deformation should be satisfactory in the longitudinal direction, when the test is coincident with the direction of rolling or hot-work of any other kind, may be vitiated in degree, if, owing to the orientation of the non-metallic matter, the tensile strength and/or the capacity for plastic deformation are adversely affected in the transverse direction. Since it is understood that for this and other reasons the steel should be as clean as possible, it follows that some quantitative method of measuring the cleanliness would be extremely valuable. Several methods have been devised, but as yet without success. This paper is submitted with a view to exploring the cause of failure of such methods, and contributing to the effort of rendering possible quantitative comparisons of the relative cleanliness of different steels.

Quantitative comparison apart, there is generally little difficulty in obtaining general agreement between the producer and the consumer as to whether a given cast of steel meets the standard of cleanliness required by the consumer.

Non-metallic inclusions are essentially of two types:—

- (a) Sulphides.
- (b) Oxides.

The amount of the former is controlled by the sulphur content of the steel; the latter come into existence as oxidation products.

There is a third source—i.e., the accidental inclusion of non-metallic matter from the refractories or from dust and dirt, but in these latter instances the resulting inclusions are of a nature distinct from those immediately under consideration.

When it is appreciated that in good open-hearth steel the total oxygen content is normally considered to be of the order of 0.006–0.009%, and that in electric-arc basic-hearth steel something of the order of 0.002–0.004%, it will be appreciated that if the sulphur content in the open-hearth steel is of the order of 0.03%, or in electric steel of the order of 0.01%, the amount of non-metallic matter arising from the sulphur is substantially greater than that which arises from the oxides. Therefore, if it is desired to produce a really clean homogeneous steel, not only must the oxidation products entangled in the metal be kept as low as possible, but, even more important still, the sulphur content must be kept at the lowest level which is practicable.

It has been said that the slag inclusion count by a well-known method would, with a constant amount of non-metallic included matter from oxidation sources, give a consistently low inclusion count—i.e., a high standard of cleanliness, although the sulphur content might be of the order of 0.04–0.05%. It is obvious that in such a case the method failed to register the degree to which the steels in question were contaminated by non-metallic inclusions. In such a case the method fails to register, within the arbitrary conditions laid down in the test, the amount of non-metallic matter existing in the form of sulphide.

A number of methods of quantitatively evaluating the non-metallic matter in steel have been put forward, and an appendix of the literature on the subject is attached to this paper. The three methods, however, to which the authors will confine their attention are the Jernkontoret, the Fox, and the Firth-Brown methods. Since the methods depend essentially on four factors these will be carefully considered on their merits—i.e.:

- (1) The selection of the sample in relation to the ingot.
- (2) The preparation of the sample, with special reference to the final preparation of the surface, which is a dominating factor.

TABLE I.—STEELS USED.

Steel.	Cast No.	Description.	Analysis.											SiO ₂ , %.	Al ₂ O ₃ , %.
			C, %.	Si, %.	Mn, %.	S, %.	P, %.	Cr, %.	Ni, %.	Mo, %.	O ₂ , %.	N ₂ , %.	H ₂ , %.		
1	52313	Extremely clean electric steel.	0.14	0.19	0.59	0.010	0.012	Trace	5.26	—	0.0028	0.005	0.00014	—	0.00918
2	66483	Clean electric steel.	0.21	0.17	0.62	0.008	0.008	0.01	3.76	0.24	0.0042	0.011	0.00011	0.0031	0.0058
3	10930	Characterised as commercial electric steel.	0.28	0.18	0.53	0.033	0.017	0.92	2.99	0.24	0.0028	0.009	0.00012	0.0056	0.0032
4	Z1823A	Characterised as very clean basic steel.	0.40	0.165	0.75	0.032	0.025	—	—	—	—	—	—	—	—
5	E6472	Characterised as commercial quality acid O.H. steel.	0.33	0.18	0.59	0.041	0.026	0.86	2.99	0.07	0.004	0.003	0.00012	0.0010	0.0048
6	19636	Characterised as clean acid O.H. steel.	0.33	0.28	0.78	0.022	0.022	0.83	3.51	—	0.0095	0.003	0.00013	0.0186	0.0080
7	19665	Characterised as clean acid Siemens steel.	0.31	0.21	0.54	0.022	0.022	0.78	3.61	—	0.0120	0.002	0.00007	0.0175	0.0025
8	W2255	Characterised as very clean acid steel, but of high sulphur content.	0.33	0.25	0.61	0.048	0.033	0.26	3.06	—	0.0026	0.005	0.00012	0.0022	0.0020

(3) Owing to the variable size in which inclusions of the same type or of different types may occur in the steel, the power of magnification is presumably a determining factor; and

(4) A critical examination of the charts purporting to represent the manner in which the inclusions occur in the steel, and to which a comparison of the actual occurrences of inclusions is referenced for quantitative purposes.

Influence of Test Factors Discussed in the Light of the Authors' Experimental Results

Data concerning the steels upon which the authors' experiments were made will be found in Table I.

(1) *The Selection of the Sample.*—For a proper consideration of the distribution of non-metallic matter in steel, it is desirable to make reference to the large number of ingot sections to be found in the various reports of the Heterogeneity of Steel Ingots Committee.¹ In the early days of those researches the layout of the sulphide inclusions was clearly brought out by the sulphur prints, but in later reports indication was given of the distribution of the silicates, as indicated by the oxygen content of the steel. The main point arising is that steel ingots are indeed heterogeneous as regards the aspects under consideration, and, further, that the ultimate bar of steel which is examined must reflect or bear relation to, in cross-section, the heterogeneity existent in that portion of the ingot which it actually represents. It has become customary to take the last ingot from the cast under examination. This ingot is rolled into blooms, varying in size from 2 in. to 5 in. gothic, and 6 in. lengths are taken from the top, middle and bottom of the chilled portion of the ingot after the discards (amounting to about 20% at the top and 5% at the bottom) have been removed. These three lengths are drawn down to 1½ in. diameter bar, from which the micro-samples are taken.

(2) *The Preparation of the Samples.*—The method of preparation of a sample for inclusion counting varies widely in different laboratories. The one adopted by the authors as being the most satisfactory for rapid routine preparation is as follows:—

A disc ½ in. thick was taken from the 1½ in. diameter bar and cut in two to reveal the axis of the bar. The sample was then hardened to facilitate polishing operations. The surface examined was ground on an old and on a new 60-grit stone. The scratches left by the smoother stone were removed on IM emery paper after the sample had been turned through an angle of 90°. The next operation was carried out either on 00 emery paper or on a slowly rotating (200 r.p.m.) cloth pad, to which coarse alumina had been applied in the form of a paste. The final polishing, which is the most critical operation, was done on a rotating disc covered with Melton cloth. This disc was moistened with water and sprinkled with a fine aluminous powder known as "Diamantine." The sample was not rotated during polishing, but was moved to and from the centre of the pad.

The function of this polishing operation is to remove the scratches left by the previous operation, and to leave the surface of the specimen in the best condition for examination. Depending on the abrasive, the polishing cloth, the pressure used and the steel which is being polished, the surface of the specimen is either "flowed," leaving a thin layer of metal in which the normal crystalline structure has been obliterated, or is cut cleanly away by the hard angular particles of the abrasive. A combination of the two may occur. If the pressure on the specimen is too light the scratches may not be removed completely, and there is a danger that the polishing material may be forced into the surface of the steel round the inclusions, making them appear larger. If too heavy a pressure is employed the surface will flow excessively and may become scorched, and the inclusions may be covered over or dug out.

It is not essential that a scratch-free surface is obtained as long as the scratches are at right angles to the direction of the inclusions and are not too deep to interfere with them. It has been found that a minimum of time on a wet polishing pad, using a very small quantity of abrasive, gives the best results.

Very interesting facts were brought out by Sir George Beilby concerning the possibility of the production by polishing of a film of indeterminate characteristics, claimed by him at the time to be amorphous. It will be interesting to consider the possible effects of the existence of such a film and its effect on some of the polished specimens under consideration.

(3) *The Influence of Magnification.*—A reference to the bibliography in the appendix given in the paper shows that different earlier investigators² in this field have used different magnifications: H. Kjerrman, 200 diameters; Herty, Christopher and Stewart, 250 diameters; and Epstein, 100 diameters; whilst Kinzel and Crafts used 50 diameters.

Of all the methods which have been advocated for quantitatively evaluating the non-metallic matter in steel, that which is known as the Fox method is perhaps the most widely used, and may, therefore, be selected to illustrate the point which is now under consideration. Bolsover³ arbitrarily laid down that the magnification to be employed for the study of non-metallic matter should be 130 diameters. To the authors' minds this always appeared to be a curious magnification to select, and would appear to have been arbitrarily determined by some local condition concerning the microscope employed. In any consideration of the effect of magnification, the obvious thing to do was to take either the Fox evaluation charts or the Jernkontoret evaluation charts and evaluate the non-metallic matter at different magnifications. The authors, therefore, proceeded to take standard micro-sections from the steels described in Table I and to carry through the standard examination at 27·5, 132, 520, 1,200 and 2,000 diameters. The inclusion "count" was taken with the specimens in the unetched condition, then again after very lightly etching with dilute picric acid (10 secs. approximately in 30% of a concentrated solution), this step being taken with a view to removing any Beilby film which might, by its existence, be preventing an accurate observation of the non-metallic matter present.

All the samples, except Z1823A and W2255, which were received in the polished condition, were prepared in the manner already described.

The Leitz Panphot apparatus was used for the counting at magnifications of 27·5, 132, 520, 1,200 and 2,000 diameters. It was considered preferable to use the visual tube of the microscope rather than the ground glass screen, as by this means the chance of small inclusions being overlooked was reduced to a minimum. It was not, therefore, possible to obtain magnifications of round figures.

The magnification of the microscope for any combination of objective and eye-piece is the product of the initial magnifications of the components used. These are stated by the lens manufacturers and are the magnifications given by the lenses at a certain distance from the optical centre of the lens combination. This distance is usually the tube length or bears a definite ratio to the tube length of the microscope. The approximate figures given by the makers' constants were used.

Owing to the different combinations of eye-pieces and objectives used for the various magnifications, the apparent diameter of the field under examination varied from 88 mm. at 27·5 diameters to 260 mm. at a magnification of 2,000. These figures correspond to a standard distance of the visual image and were obtained by multiplying the diameter

¹ H. Kjerrman, *Jernkontoret's Annaler*, 1909, **113**, p. 181.

² C. H. Herty, jun., C. F. Christopher and R. W. Stewart, *Mining and Metallurgical Investigations*, 1930, *Co-operative Bulletin* No. 38.

³ S. Epstein, *Metals and Alloys*, 1931, **2**, Oct., p. 186.

A. B. Kinzel and W. Crafts, *American Institute of Mining and Metallurgical Engineers*, 1931, *Technical Publication* No. 402.

⁴ G. R. Bolsover, *METALLURGIA*, 1935, vol. 12, July, p. 83.

¹ Reports I to IX, published at the Offices of the Iron and Steel Institute, 1926 to 1930.

of the field subtended by the objective on the specimen, by the magnification. At magnifications of 132 and 520, the fields were of a reasonable size—108 mm. and 104 mm. in diameter, respectively—but at 1,200 and 2,000 diameters they were too large to be conveniently examined or accurately compared with the Fox standard fields, which were 58 mm. in diameter. Therefore, by means of a field diaphragm, the diameters of the fields were reduced to 108 mm. and 110 mm.

It might not, at first, be considered that the field diameter could affect the count, but it must be realised that the counts are arrived at by comparison with standard fields. A large field containing, say, 20 well-distributed inclusions would tend to cause the observer to put the count higher than if a portion of the same field having half the diameter and a quarter of the area were graded. This field would contain five inclusions. Differences in the apparent fields used by different investigators have probably caused some of the variations in inclusion counts that have been noticed in the past.

To make sure that the same areas, as nearly as possible, were examined each time, two lines were scribed across the specimens from 3 mm. to 5 mm. from each edge, and the counts taken on strips between these lines and as close to them as possible. Two runs were made across the samples at the $\times 27.5$ and $\times 132$ magnifications, but only one at the higher powers, with the result that about 24 fields were graded for each count at $\times 27.5$ and about 450 fields at $\times 2,000$. These were totalled up, and the average field value was found. The figures reported in Table II were reduced to a basis of 60 fields as in the normal Fox count.

It appeared quite likely that the polishing process might cover over some of the finer inclusions and result in a lower count than the actual cleanness of the steel justified. After the steel had been examined in the as-polished condition it was lightly etched in dilute picric acid in methylated spirit (30% of a saturated solution) until the surface was just clouding over. The specimen was then very lightly touched up on a clean polishing pad of Melton cloth. Marked increases in inclusion counts were obtained on some samples after the light etch.

The averaged results obtained are given in Table II under lines A. Contrary to the expectation that the inclusion count would be higher on increasing the magnification, and

that inclusions would be brought into view that could not previously be seen, the count shows a steady decrease as the magnification increases. This is attributed in part to the fact that the standard charts are not in accord with geometrical principles. Whilst the area of inclusion matter is small compared with the area of steel, for an increase in magnification, the inclusions are dispersed more widely, but in exactly the same proportion as the increase in size of the inclusions. It has been claimed that over a range the exact magnification used for the Fox count does not affect the result. In accordance with geometrical principles, this would be accepted, and one would anticipate that this statement could be extended over quite a large range of magnifications. Such a statement naturally assumes that the charts for comparison would be such that this principle could be applied. That the charts depart from this principle is shown by the results of the counts at different magnifications, and the tendency for the counts to become less, the higher the magnification. This has been demonstrated in another manner:—

Photographic reproductions have been made of some of the standard fields at a magnification of 4 diameters. These have been divided into fields of the same size as the originals, treated as samples for inclusion count, and graded against the Fox standards. A field of grade 2 gave a count of 11 for 16 fields or a total count of 41 on 60 fields, and a field of grade 3 gave a 24 count on 16 fields or 90 on 60 fields. These figures of 41 and 90 are quite different from the values of 120 and 180 that would be expected if the standards had been constructed geometrically.

As regards the counts at $\times 27.5$, the inclusions were, in the majority of cases, very fine, besides being very numerous, so that only a very rough comparison could be made between them and the Fox chart.

It will be noticed that in some cases there is a decrease in count after the light etch. This is in most cases due to the plus or minus variations in the count that are normally expected when counts have been taken at different times. This may be partly due to the examination of a slightly different line on the specimen.

When the results had been considered, it was felt necessary to include figures for two intermediate values, and therefore the samples were *repolished* and examined at 82 and 250 diameters with a recheck on the values given for 130

diameters. This step led to important results, and the figures are given in the lines marked B in Table II, both as polished and as subsequently lightly etched. This work, it must be remembered, was carried out by the same investigator and with great care, but a different order of counts was obtained in the polished condition.

Take, for instance, steel No. 3 (10930). On repolishing a count of 61-62 became a count of 37-35.6. These effects are apparently due to a new polishing cloth, and although two days were spent in trying to get the cloth into condition, the results were as indicated. Maybe the condition of the cloth was conducive to the production of the Beilby layer and the obscuration of certain inclusions.

(4) Critical Examination of the Quantitative Validity of

TABLE II.—INCLUSION COUNTS.

Steel.	Condition of Section.	Magnification.						
		$\times 27.5$	$\times 82$	$\times 132$	$\times 250$	$\times 520$	$\times 1200$	$\times 2000$
1. 32313. "Extremely clean" electric arc basic hearth.	Unetched A	5.5	—	13.0	—	7.6	7.8	6.0
	B	—	12.25	11.35	11.25	—	—	—
	Etched A	17.0	—	17.0	—	9.0	6.7	5.5
2. 66493. "Clean" electric arc basic hearth.	B	—	11.0	8.0	8.0	—	—	—
	Unetched A	20.8	—	17.2	—	14.0	10.2	8.0
	B	—	20.9	18.5	20.3	—	—	—
3. 10930. "Commercial" electric arc basic hearth.	Etched A	25.0	—	25.0	—	15.4	9.5	8.0
	B	—	18.0	18.0	19.0	—	—	—
	Unetched A	68	—	61.5	—	48	31.8	29.0
4. 21825A. "Very clean" basic open-hearth.	B	—	35.5	36.2	41	—	—	—
	Etched A	69	—	62.0	—	40.5	37.0	30.0
	B	—	75.0	70.0	65.5	—	—	—
5. 10930. "Commercial" quality acid open-hearth.	Unetched A	11.4 (30)	—	32 (41.2)	—	24.6 (43.4)	23.5 (41)	17.1 (34.1)
	B	—	48.5	42.0	40	—	—	—
	Etched A	67.0	—	68.0	—	49.5	45.0	33.8
6. 19636. "Clean" acid open-hearth.	B	—	56.0	57.0	62	—	—	—
	Unetched A	120	—	100.5	—	47.6	37.4	27.0
	B	—	82	71.0	61.5	—	—	—
7. 19665. "Clean" acid open-hearth.	Etched A	122	—	105.0	—	51.8	34.5	29.1
	B	—	89	85.5	64.0	—	—	—
8. 19636. "Clean" acid open-hearth.	Unetched A	102	—	79.2	—	47.0	33.4	27.0
	B	—	64.5	57.0	50	—	—	—
	Etched A	68	—	75.0	—	41.0	35.0	30.1
9. 19665. "Clean" acid open-hearth.	B	—	92.0	88.5	71	—	—	—
	Unetched A	94.5	—	77.0	—	46.5	38.2	28.0
	B	—	56	52.5	52	—	—	—
10. W2255. "Very clean" acid steel, high sulphur.	Etched A	83.0	—	79.0	—	45.0	40.0	33.2
	B	—	70	74.0	66	—	—	—
11. W2255. "Very clean" acid steel, high sulphur.	Unetched A	21 (60)	—	25 (67)	—	27 (53)	33 (42)	24 (37)
	B	—	58.0	46.0	50.7	—	—	—
	Etched A	50 (58)	—	74 (72)	—	56.5 (50)	55 (48.5)	45.3 (38)
12. W2255. "Very clean" acid steel, high sulphur.	B	—	95.5	76.0	76.0	—	—	—

the Comparison Charts.—In this connection a quantitative examination of the Jernkontoret chart⁴ and the Fox chart⁵ was made, the object of this quantitative study being to determine whether or not the quantities of inclusions represented on these charts were present in the different grades in the ratios which are given—i.e., 1, 2, 3, 4, 5 or 1, 2, 3, 4—since these ratios are quantitatively reflected in the inclusion count.

Images of the various grades were projected on to a screen, and the outline of the inclusions was drawn on paper placed on the screen. Pieces of paper of the size of the inclusions were cut out and weighed, the weight being proportional to the area of inclusion matter present.

There are forty diagrams in the Jernkontoret chart. These are divided into five different grades, with eight standard fields in each grade. These represent four types of inclusion:

- A.—Sulphide.
- B.—Aluminium oxide.
- C.—Silicates.
- D.—Certain oxides.

Two examples are given in each inclusion type, the inclusions in one being of a different thickness from the others. These thicknesses are represented by the letter μ and are only arbitrary examples. The results, which are given in Table III, show wide variations.

The figures given are actually weights in grammes, but are proportional to the areas of inclusions present in the standard charts.

TABLE III.
JERNKONTORET CHART.

Grade.	A.		B.		C.		D.	
	4 μ .	6 μ .	9 μ .	15 μ .	5 μ .	9 μ .	8 μ .	12 μ .
1	0.0222	0.0260	0.0112	0.0293	0.0206	0.0281	0.0119	0.0258
2	0.0534	0.0826	0.0330	0.1000	0.0454	0.0636	0.0340	0.0859
3	0.1280	0.1930	0.0900	0.2730	0.0791	0.1120	0.0634	0.1338
4	0.2673	0.3700	0.1653	0.4594	0.1471	0.1969	0.0874	0.2462
5	0.1090	0.6226	0.3769	1.1790	0.2848	0.3782	0.1528	0.3145

TABLE IV.
FOX CHART.

Grade:	1.	2.	3.	4.
(a)	0.086	0.23	0.87	1.27
(b)	0.136	0.38	0.90	3.01
(c)	0.15	0.19	0.77	1.32

It has been found by this method of measuring the areas of the inclusions in the standard fields of the Fox chart (Table IV) that the average area of inclusion matter in each of the four grades, instead of being in the ratio of 1:2:3:4 as would be expected, is in the ratio 1:2.15:6.83:15.0. Even so, this quantitative aspect is only two- instead of three-dimensional.

Figures have been worked out for 20 selected electric and 20 selected open-hearth casts of steel on this basis. The electric-steel casts were specially selected in that they contained No. 2 and No. 3 fields (and an occasional No. 4). A far greater number of casts contained only fields of grade 1 or not more than three fields of grade 2 and were not included. In this greater number of cases, the new basis for count would not alter the count figure.

The old and new results for the electric and open-hearth casts are given in Table V.

It will be seen that the non-quantitative nature of the reference chart, if used in a quantitative manner, as is practised, leads to an erroneous gradation of the steels as regards cleanliness.

TABLE V.
OLD AND NEW COUNTS ON ELECTRIC AND OPEN-HEARTH STEELS.

Electric Steel.				Siemens Steel.			
Cast No.	Count.			Cast No.	Count.		
	Old Fox Basis.	New Basis.	Increase		Old Fox Basis.	New Basis.	Increase.
53629	35	51	16	19147	116	146	30
60519	65	78	13	19196	110	131	21
62121	45	54	9	19200	128	167	39
64726	57	66	9	19228	118	141	23
65799	48	57	9	19255	108	115	7
66920	56	61	5	19322	82	93	11
67009	46	47	1	19334	90	94	4
67084	37	45	8	19351	100	113	13
67110	49	69	20	19405	122	160	38
67129	40	44	4	19407	94	121	27
67140	39	50	11	19427	91	96	5
67191	45	57	12	19458	90	95	5
67283	65	79	16	19501	100	120	20
67228	57	69	12	19502	118	155	37
67657	64	66	2	19511	86	90	4
67684	150	269	119	19517	114	130	16
68176	51	52	1	19535	124	197	73
68202	40	44	4	19879B	91	104	13
68350	51	51	0	19879W	104	119	15
68443	84	88	4	19908	112	123	11

Consideration of the Results

For a proper consideration of the results disclosed in Table II it is necessary to study each steel in detail.

Steel No. 1, Cast No. 52313, was included as representing perhaps the cleanest steel that the authors had ever examined. It was manufactured in the arc furnace on a basic hearth in their own works. It is a 5% nickel case-hardening steel; the sulphur content is 0.010%, and the oxygen content 0.0028%.

Steel No. 2, Cast No. 66483, is an electric-arc steel made on a basic bottom. It is a nickel-chromium-molybdenum steel, regarded as quite clean by the Ingot Committee, and adopted by them for comparative mechanical test purposes. It has a sulphur content of 0.008%, with an oxygen content of 0.0042%. This was made in the authors' own works.

Steel No. 3, Cast No. 10930, is an example of an electric-arc steel made on a basic hearth, which was bought in the open market as representative of commercial practice. It is a nickel-chromium-molybdenum steel, and the suppliers delivered the billets from stock. The sulphur content is 0.033% and the oxygen content 0.0038%.

Steel No. 4, Cast No. Z1823A, is an example of basic open-hearth steel, considered to be "very clean." The sulphur content will be noted as 0.032%. This sample was supplied by another company. In this case the material is simply a carbon steel.

Steel No. 5, Cast No. E6472, was supplied from billets in stock by another firm, as representing commercial-quality acid open-hearth steel. This is a nickel-chromium-molybdenum steel; the sulphur content is 0.041%, but the oxygen content is only 0.004%.

Steels Nos. 6 and 7, Casts Nos. 19636 and 19665, are representative of acid open-hearth steel of high standard, produced according to a long-established practice in the authors' own works. These two materials are nickel-chromium steels; in both cases the sulphur content is 0.022%, and the oxygen contents are 0.0095% and 0.012%, respectively.

Steel No. 8, Cast No. W2255, is another acid Siemens steel, produced in another works, which was considered to be an instance of very clean steel, in spite of the high sulphur content. This material is a 3% nickel steel; the sulphur content is 0.048%, and the oxygen content very low at 0.0026%.

This set of steels constitutes an extremely interesting series, and the figures obtained in the form of inclusion counts require to be studied in great detail. The results obtained by the authors indicate once more that generally any piece of painstaking research tends to yield some new and interesting aspect.

The examination of steel No. 8, cast No. W2255, was particularly instructive. The sample was first of all counted

⁴ R. Rinman, H. Kjerrman, and B. Kjerrman, "Inclusion Chart for the Estimation of Inclusions in Steel," Uppsala, 1936: Almqvist and Wiksells Boktryckeri A.-B.

⁵ B. Bolsover, *loc. cit.* The actual experimental work was carried out on a chart issued by Samuel Fox and Co., Ltd., with a brochure entitled "The 'Fox' Inclusion Count."

as received and counts of a very low order were obtained (25 at 132 diameters), and in this instance the low count seemed to be independent of the magnification. The light etching, however, immediately increased the count to a value similar to that obtained from the other acid Siemens steels. The surface of the specimen was, therefore, re-prepared and again counted in the polished condition, when, as will be seen, much higher values were obtained, but, on etching, practically the same value was obtained as on etching the sample as received. The figures in brackets were obtained with the specimen as received and are counts obtained by the authors after a preliminary repolish. In the same connection, the results from steel No. 3, cast No. 10930, are worth studying, since the second time the specimen was prepared a count of little more than half the value representing the condition as first prepared was obtained, whilst after the light etching the results came substantially into line.

The authors do not propose to discuss all the figures from each steel in detail, but would ask readers to refer to Table II.

As the magnification increases above 80 diameters, there is a tendency for the inclusion count to decrease. At 27.5 diameters the results are somewhat variable, owing to the inclusions appearing very small at this magnification, and the difficulty in accurately comparing a large number of extremely fine inclusions with a chart containing about twelve larger ones.

Etching the samples results in an increase in the inclusion counts in most cases. This is particularly noticeable in casts Nos. Z1823A and W2255, in which the inclusions are very small sulphides, such as may easily be covered over by the polishing operation if care is not taken. That this effect can be reproduced by very heavy polishing on a new cloth is shown markedly by the B counts on casts Nos. 10930, 19636, 19665, and W2255, at the magnifications of 82, 132 and 250 diameters. In each case the counts fall in line with the others after lightly etching.

There are cases where the count after etching is a little lower than that beforehand, and where there are variations in counts at a given magnification of the order of 10%. This is due to the usual margin of error allowed in this count when the readings are taken at different times or by different people.

The count of 102 for cast No. 19636 at 27.5 diameters may seem rather high when compared with the figure of 68 obtained after etching. This magnification is too low for the accurate counting of small inclusions, it being very difficult to distinguish the inclusions from polishing imperfections, which latter are not noticeable after etching, and can be recognised at greater magnifications if they are visible. If attempts were made to remove these imperfections by further polishing, there would be a risk that some of the inclusions might be obscured.

The effect of the magnification on the order of cleanness of the casts is remarkable. Apart from the very clean steels Nos. 52313 and 66483, cast No. W2255 heads the list as cleanest at 27.5 diameters. As the very fine inclusions become visible at the higher magnifications, its position in the list sinks, until it is the dirtiest steel at 250 diameters and over. Cast No. Z1823A, which contains similar inclusions, maintains its high position in the list up to 520 diameters, when it is the third from the bottom, sinking to the bottom but one at 1,200 and 2,000 diameters. On the other hand, cast No. E6472 progresses from the dirtiest cast at 27.5 diameters, and at the standard magnification of $\times 132$, to the third cleanest at 1,200 and 2,000 diameters.

This can be summed up by saying that as the magnification increases, the steels which are lowest on the list at the beginning gradually "improve" in cleanness and the "cleaner" steels gradually grow "dirtier."

Conclusions

The practical object of this investigation was to assess this very interesting series of steels from the standpoint of

cleanliness—i.e., relative freedom from non-metallic matter. It will be seen that steels Nos. 1 and 2 appear to stand out, as far as can be ascertained by this line of attack, as very clean steels. The interesting conclusion, however, at which the authors invariably arrive is that as regards steels Nos. 4, 5, 6, 7 and 8, there is very little distinction in the degree of cleanliness.

The prime object of inclusion counting is to obtain a quantitative valuation of the relative cleanliness of one steel compared with another. It has been claimed that if the procedure in counting is uniform several investigators will obtain the same values, and this, within limits, is agreed. But if the method is based upon intrinsic fallacies and on non-quantitative data, reasonable agreement on the figures arrived at is none the less of little value in assessing the relative cleanliness.

The standard charts are not sufficiently varied in regard to types of inclusions, and whilst the ratio of the count values of the fields in the different grades are 1, 2, 3 and 4, the areas of inclusion matter given are in quite different proportions.

Large inclusions may cover as many as six fields vertically, and whereas only one, or at the most two, such fields would be counted by the method, the steel would instantly be rejected by most users, without any indication being given in the count.

The present method of inclusion counting is misleading in the interpretation that it gives of the amount and nature of the non-metallic matter. With certain steels, if the specimen is lightly etched to remove the Beilby layer which obscures the non-metallic matter, the materials may be placed in an entirely different order of cleanness, and some steels which had been classed as clean could be characterised as dirty. This effect is particularly noticeable where the inclusions are very fine sulphides which have undergone a great deal of elongation by rolling.

By altering the magnification at which the inclusion count is taken, the relative grading of the cleanness of the steels is completely modified, and there seems to have been little justification for the magnification arbitrarily chosen by the sponsors of the test.

The standard charts are not on a satisfactory quantitative basis.

Some time ago the authors devised a modification in the method of counting to take care of the difficulty that the count at the outside of the bar was representative of a far greater volume of steel than a count at the centre. In the Firth-Brown count, therefore, a diametrical cross-section of the bar was divided into ten zones, numbered E1, D1, C1, B1, A1, A2, B2, C2, D2, E2. About four fields were examined in each of these zones, and graded according to the Fox chart. The average cleanliness of each zone was calculated and multiplied by its "volume factor"; these were 1, 3, 5, 7 and 9, for the zones A to E, respectively. The total of these products was divided by 100, and the result expressed in the form of an "average field" with regard to the Fox chart. This method fell into disuse on the grounds that it was too complicated and that the advantage obtained through the introduction of the "volume factor" was outweighed by the inaccuracy in grading, due to the method of grading employed, which was subject to the same disadvantages as was the Fox method.

It is indeed difficult to see what lines can best be followed to produce a method which will give reliable quantitative indications of cleanliness, but the authors hope that this account of their own efforts to explore existing methods will at any rate have pointed out some of the disabilities which have to be overcome.

The field of study is an extensive one, since not only would it be of value to have some quantitative method of determining the amount of non-metallic matter present, but it is also important to evaluate the influence of the different types of inclusions upon the characteristics of the steel.

The Corrosion of Mild and Copper-Bearing Steel Panels in Iron-Ore Wagons

By L. Reeve, Ph.D., B.Sc.

The losses in weight of a series of mild-steel and copper-bearing mild-steel panels fitted in the end plates of three 21-ton steel iron-ore wagons are compared over a period of nearly three years. The results indicate that at the end of the period the average loss in weight of the copper-steel panels amounts to only 38% of that of the mild steel. This report is Paper No. 3/1940 of the Corrosion Committee of the Iron and Steel Institute and the British Iron and Steel Federation, communicated by Dr. T. Swinden to the Autumn General Meeting of the Iron and Steel Institute.

THE beneficial effect of a small addition of copper to mild steel in resisting corrosion under various circumstances is generally recognised. This report presents the results of three years' corrosion tests on panels of mild and copper-bearing steel inserted in the end-plates of hopper-type ore wagons.

The wagons are of 21 tons capacity and have been on main-line service, transporting ore between the Appleby-Frodingham Steel Company's mines and its blast furnaces, from April, 1937, till September, 1939. Since then they have been on internal service, transporting ore within the Company's Scunthorpe Works. The total mileage covered in their life is approximately 20,000 miles per wagon.

Apart from fittings, the wagons are of all-welded construction, and for the purpose of these tests a suitable frame was welded into each end-plate to carry the test panels, as shown in Fig. 1. The panels were bolted into position with countersunk bolts, and were arranged to be flush with the inner surface of the end-plate.

The panels were unpainted except for identification marks on the outside, and an additional means of identification was provided by saw cuts in the top edges of the panels. Correct replacement of the test-plates was also ensured by adopting a slightly irregular arrangement of the bolt holes, the positions of which varied slightly for each wagon and each end.

Three wagons were constructed in this manner, with a mild-steel panel at one end and a copper-bearing panel at the other end of each. The wagons were actually of copper steel throughout, except for the end-plate carrying the mild-steel test panel, which was itself made of a similar mild steel; the frame carrying this panel was also of mild steel.

The analyses of the test panels are recorded in Table I.

The mild steel M, being made from virgin ore without outside scrap additions, is low in copper and other residual alloys. The copper-bearing steel K is similar, but has a copper addition of 0.38%.

TABLE I.
ANALYSES OF TEST PANELS.

Wagon No.	Panel No.	C, %	Si, %	S, %	P, %	Mn, %	Cu, %	Cr, %	Ni, %
F 114	M 1	0.16	0.014	0.045	0.028	0.62	—	—	—
	K 2	0.14	0.024	0.052	0.041	0.55	0.38	—	—
F 115	M 3	0.16	0.019	0.044	0.026	0.64	0.023	0.047	0.045
	K 4	0.14	0.028	0.053	0.042	0.51	0.39	0.054	0.049
F 113	M 5	0.15	0.017	0.045	0.027	0.62	—	—	—
	K 6	0.15	0.024	0.053	0.041	0.55	0.38	—	—

The panels were 2 ft. 10 in. long by 1 ft. 4 in. wide by $\frac{1}{4}$ in. thick, and weighed approximately 40 lb. each. They were weighed to the nearest ounce on Avery platform scales (counterpoise-arm type) of one hundredweight capacity, the first weighings being as shown in Table II.

Subsequent weighings were made at approximately six-monthly intervals after the panels had been scrubbed with a dry wire brush, which easily removed all loose "granular" rust and adherent ore, but did not remove any tightly adherent scale. Whilst this is not an absolute method of determining true scaling, it is the only convenient method when working with large panels. Moreover, it corresponds fairly closely to service conditions, where loose scale is removed by the abrasive action of the masses of ore in the wagon.

A new brush was used on all the panels at each weighing, and the scrubbing was done by the same operator. It is felt, therefore, that the results are comparable, and their

Fig. 1.—Iron-ore hopper wagon, 21 tons capacity.

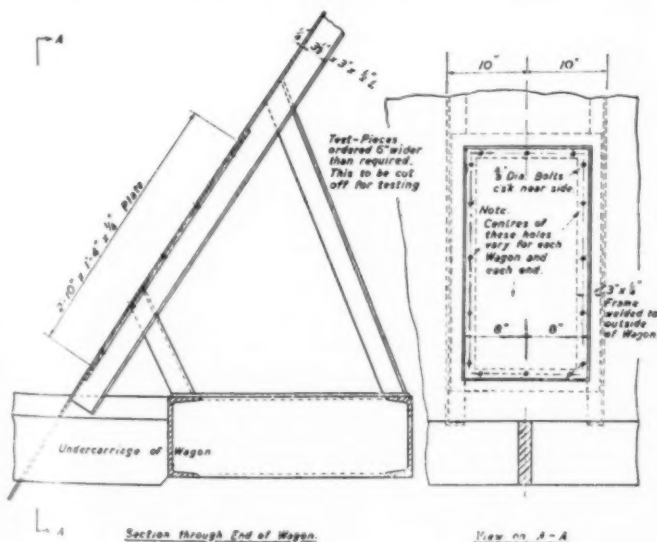
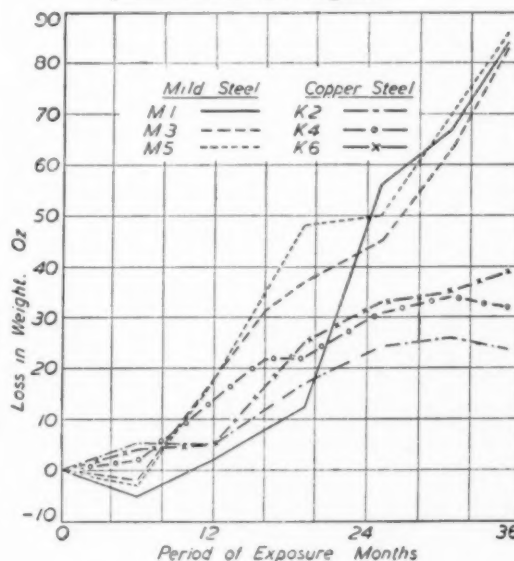


Fig. 2.—Corrosion tests on mild- and copper-steel panels in iron-ore wagons.



general trend is confirmed by the reasonable agreement between the three sets of results after the first nineteen months of service.

The detailed results for nearly three years' service are given in Table II, and are plotted in Fig. 2.

TABLE II.
THREE YEARS' CORROSION TEST RESULTS.

Wagon No.	Panel No.	Original Weight (22.4.37).	Total Change in Weight, Oz., After Exposure for Approximately—							
			6 Months.	12 Months.	18 Months.	19 Months.	25 Months.	30 Months.	35 Months.	
F 114	M 1	40 8	G 5	G 2	—	L 12	L 56	L 67	L 84	
	K 2	39 9	L 5	L 5	—	L 17	L 24	L 26	L 24	
F 115	M 3	39 7	G 2	—	L 31	L 57	L 45	L 63	L 83	
	K 4	38 4	L 2	—	L 22	L 22	L 31	L 34	L 32	
F 113	M 5	40 6	G 3	L 18	—	L 18	L 50	L 70	L 86	
	K 6	39 15	L 4	L 5	—	L 25	L 33	L 35	L 39	

G = Gain in weight. L = Loss in weight.

It will be noted that whilst the mild-steel panels M are continuing to lose weight steadily, the copper-bearing

panels K have slowed down to a very low rate of loss. This is partly accounted for by the fact that the scale on the latter is tightly adherent to the underlying plate and exerts a certain amount of protective action upon it.

The mild-steel scale, however, comes off fairly easily, and this no doubt occurs in service by impact and abrasion by the hard masses of ore. At the end of approximately three years, the average loss in weight of the copper-steel panels amounts to only 38% of that of the mild steel and is getting relatively even smaller.

The tests are being continued, but unless a sudden change occurs they will be stopped at the end of the fourth year, when the plates will be given a careful laboratory examination, including a final descaling in Clarke's solution to determine the residual scale.

Meantime, there would appear to be no doubt of the economic value of copper steels in wagons of the type described under conditions of combined corrosion and mild abrasion. It is hoped to extend the tests to other types of mineral wagons in the company's service.

Nitrided Stainless Steels

IT is well known that many special types of alloy steels have been developed which can be nitrided to produce an exceedingly hard surface. The surface hardness obtained by this process is much greater than is obtainable with steel hardened by any other method. Although the special alloy steels developed for this process of surface hardening are not included in the stainless steel category, certain compositions of steel in the nitrided condition have shown good resistance to the corrosive action of fresh and salt water, steam, or moist atmosphere. It has long been recognised, however, that if the corrosion-resisting properties of the stainless steels could be combined with a hard, abrasion-resistant surface, the field of usefulness of these alloys would be further extended, and this combination of properties would materially improve stainless machinery parts and other stainless articles where resistance to wear is required. It is noteworthy that, according to Horace Drever,* a practicable method for surface hardening these steels has been developed and is now available.

In the new process of nitriding the stainless steels which has been developed, the outer layer of the material is impregnated with nitrogen, presumably in the form of nitrides, to a depth that varies with the type of steel and the time under treatment. It is found that in general a depth of 0.008 in. to 0.050 in. will suffice for the great majority of purposes, the depth of case being determined individually for the type of service to which the article will be applied. Some types of steels will nitride more readily than others, and, in general, the steels that have no nickel present will be more readily nitrided than those with nickel, under the same conditions of time and temperature.

The process is carried out in furnaces of orthodox type at moderate temperatures—i.e., approximately 540° to 600° C. A muffle that can be made entirely gas-tight is used, and the processing gas let in or out in the usual manner of nitriding, with an effort made to keep approximately constant pressure throughout the process. The gas used is derived from anhydrous ammonia, and is used in two states. During the preliminary part of the cycle the ammonia vapour is dissociated, and after purification and activation is admitted to the nitriding chamber to sweep out all traces of air that may be present. After this preliminary purging, ammonia vapour, after being activated in a silent electrical

discharge to ionize the gas, is admitted to the nitriding chamber. In the actual nitriding, ammonia gas is dissociated partly, the nascent nitrogen being absorbed by the material and the hydrogen that is released passing out of the muffle together with the undissociated gas. The essential of the process is the ionization of the gas before admittance to the nitriding chamber. This is covered by several patents.†

The new process is claimed to be quite flexible, and can be adopted to treat parts of special and intricate design. Since the surface hardness depends on gas penetration and absorption, it is possible to harden keyways, tube or bearing interiors and in fact any surface which can be exposed to the gas. However, if it is desirable to harden one section and retain a soft surface elsewhere, means are available for inhibiting or stopping off these surfaces and preventing their hardening. Hardnesses up to 1,050 Vickers Brinell are secured, and it is found that these hardnesses are maintained to a relatively high degree at elevated temperatures. For instance, a sample of 18/8 stainless steel was nitrided to a depth of 0.010 in. and tested on the Vickers machine, with the following results:—

Test Temperature.	Vickers Hardness.
70° F.	1,050
1,000° F.	710
1,100° F.	540

No indication is given how long the nitrided part was held at the elevated temperature given, or the effect of intermittent heating on the hardened surface, nor is full information yet available on the corrosion resistance properties of the treated surface, but sufficient has been done to indicate that the process will increase the scope of stainless steels for special purposes where resistance to abrasion as well as to corrosion is desired.

New Metallurgical Combine for Urals

PREPARATORY work is now in progress for the building of a big metallurgical combine, the site of which is located some eight miles from Orsk in the Urals. The combine will have four super-powerful blast furnaces, each of a volume of 45,900 cub. ft. Their combined output will be 1,200,000 tons of pig iron a year. The projected capacity of the open hearth shop and rolling mill is 1,000,000 tons of ingot steel and 800,000 tons of rolled metal. In addition, the combine will include a coke-oven plant (capable of producing 2,000,000 tons of coke a year), ore mines, enriching and agglomeration plants.

* *Metals and Alloys*, 1940, Vol. 12, No. 3, pp. 271-3.

† U.S. Patent No. 1,975,003, Sept. 25, 1934. U.S. Patent No. 1,975,064, Sept. 25, 1934. U.S. Patent No. 2,131,709, Sept. 27, 1938. U.S. Patent No. 2,131,710, Sept. 27, 1938. U.S. Patent No. 2,188,137, Jan. 23, 1940.

Forging Monel, Nickel and Inconel

Nickel and high-nickel alloys are being increasingly used for a wide range of high-duty purposes under difficult service conditions, and to work these materials successfully it is necessary to develop the proper technique. They can be forged into a great variety of products, and in this article is given data and information to facilitate this operation. Proper heating is essential and attention is directed to fuels and furnace conditions.

MONEL,* K Monel,* Nickel and Inconel* can be forged readily, in dies or by hand methods, into almost any shape that can be forged in steel. Die forgings such as conveyer chain links and hooks are made regularly, and hammer forgings are produced in a great variety of products, including large-diameter bars for shafting and hollow-bored tubing, seamless forged rings, pickling hooks, and other common shapes. Pipe fittings, valves and the like can be produced as hydraulic or mechanical press forgings.

Forgings of Monel, nickel and Inconel are stronger than those made of bronze, or of carbon steel that has not been heat-treated subsequently. Corrosion-resisting forgings having unusually high physical properties can be made from K Monel, which can be hardened by thermal treatment. Since its forging characteristics do not differ materially therefrom, it is handled in the same way as ordinary Monel.

The successful forging of these metals depends largely upon proper heating. With good heating conditions and the right temperatures, Monel, nickel and Inconel can be forged easily into finished products of the highest quality, with no losses above the normal proportion for similar forging work in steel.

Proper heating involves not only the temperature and the time of heating, but also control of the furnace atmosphere, which is accomplished through correct combustion and the use of appropriate fuel.

Fuels

The most important difference between the heating of materials of high-nickel content and materials such as carbon steel, chromium steel and the bronzes, is the greater susceptibility of the former to attack by sulphur during heating. With the high-nickel materials, exposure of the hot metal to sulphurous atmospheres or other sources of sulphur must be avoided scrupulously. Metal surfaces that have been attacked by sulphur at high temperatures have a distinctly burned appearance, and if the burning is at all severe the material is weakened mechanically and rendered useless. A sample that has been affected by sulphur, and also one that has not, are shown in Fig. 2.

The most common source of sulphur is the fuel, and consequently care should be taken to avoid the use of fuels containing much of that element.

Oil

Oil is the fuel most generally used by forge shops for heating Monel, nickel and Inconel. It should be purchased

*Registered Trade Marks.

Fig. 1.—Drop forgings for steam valves of Diamond Soot Blowers. Left-hand and central groups are of K Monel; the two discs on the right are of regular Monel faced with Stellite.

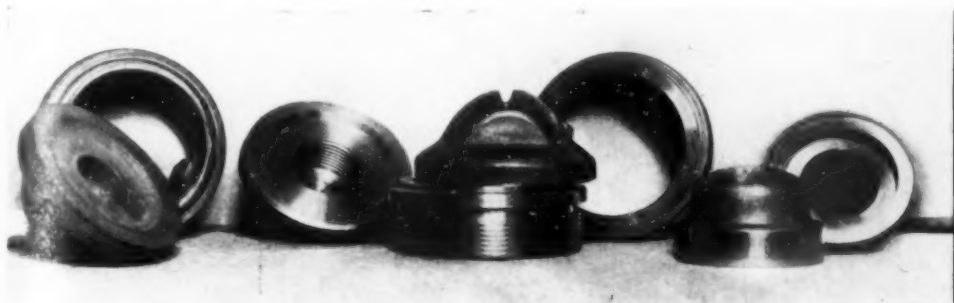


Fig. 2.—Cold bend tests on Monel rivet stock. The 180° bend was obtained on a piece heated in a sulphur-free atmosphere. The other piece was heated in a coal-fired, bar-heating furnace. The embrittlement is due to the sulphur present in the coal.

on a specification calling for the lowest possible sulphur content, 0.2 to 0.3% being a reasonable figure, although the actual permissible minimum depends very largely on furnace conditions. If the furnace atmosphere is reducing, then the slightest trace of sulphur is most detrimental. On the other hand, if the furnace conditions are oxidising, sulphur in small quantities has little or no detrimental effect on the metal being heated. Further reference to this matter is made later on.

Any good burner that will mix the oil and air supply thoroughly, and that can be regulated closely, should be suitable for heating these metals. Burners that utilise low-pressure air, supplied through the burner, are superior to high-pressure burners, or to those of the steam-injector type. Burners of the low-pressure type work well with temperature control equipment.

Gas

Gas is the most suitable fuel for heating Monel, nickel and Inconel, and should always be used if available. Good results can be obtained readily with gas because of the ease with which it can be mixed thoroughly with the air, and its supply can be controlled. Gas fuel requires only a small combustion space, and automatic regulation of temperature and furnace atmosphere can be accomplished easily. The convenience, simplicity and ease of control in modern furnaces equipped with mixers to proportion automatically the gas-air mixture over the full range of heat demand give

Fig. 3.—Hot-forged Monel head for oxy-acetylene cutting torch.



an important advantage to gas in terms of good heating and high yields.

City gas, which is very low in sulphur, is a satisfactory fuel for Monel, nickel and Inconel. It is used especially in small furnaces for heating small forgings, ornamental work, bar ends for hot heading rivets and bolts, and other light work. Its good qualities justify its relatively higher B.T.U. cost.

TEMP.		METAL			HEAT COLORS
°C.	°F.	INCONEL	NICKEL	MONEL	
1316	2400				Light Yellow
1260	2300				
1230	2250				Orange Yellow
1177	2150				
		Best Forging Range	Best Bending		Orange Red
1038	1900				
1010	1850				Bright Cherry Red
		Light Blow		Light Blow	
871	1600				Cherry Red
		Best Forging Range	Best Bending		
		Light Blow		Light Blow	Dull Cherry Red
		Best Forging Range	Best Bending		
640	1200				Dark Red
		Best Forging Range	Best Bending		
535	1000				Red (Visible in Daylight)
		Best Forging Range	Best Bending		
379	750				Red (Visible in Daylight)

Fig. 4.—Approximate temperature ranges for forging and bending Monel, nickel and Inconel.

Two other very satisfactory gaseous fuels are butane and propane. While their cost on a B.T.U. basis is higher than that of oil, their ultimate cost per pound of finished forgings may easily be lower. Butane can be considered in a sense as an oil fuel of high volatility, and proper means must be provided for gasifying it, by heating before it is mixed with air for combustion. Propane is more volatile, and does not require the application of heat to convert it from liquid to gas. It is obtainable in cylinders, which should be equipped with pressure regulators to control the flow of gas. These cylinders are particularly useful for occasional work in heating Monel, nickel or Inconel for forging, hot-forming and riveting.

Coal and Coke

Coal and coke are generally unsatisfactory for heating nickel and high-nickel alloys. Coal is, in most localities the cheapest source of heat on a B.T.U. basis, but it is almost certain to be the most expensive when compared with oil, gas, and even electricity, on the basis of total heating costs if rejections, additional metal required to provide for scaling losses, and higher finishing costs are included.

The solid fuels are unsatisfactory because of the difficulty of providing for proper heating conditions, inflexibility in heat control, and the presence of sulphur in excessive amounts. Heating in a blacksmith's hearth is almost

impracticable, and will be almost certain to lead to disastrous failures.

When it is necessary to heat in a forge burning high-sulphur fuel, it is essential that the metal be protected by placing it in a steel pipe, which serves as a muffle and avoids contact with the solid fuel or gases of combustion. The pipe must be long enough to extend beyond the fire, thus preventing the gas from sweeping into the pipe. Obviously

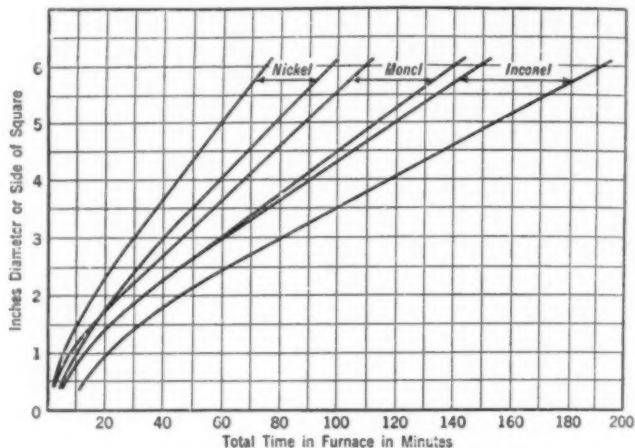


Fig. 6.—Approximate time required for heating Monel, nickel and Inconel bars of different sectional dimensions.

this method is not applicable to the reheating of bent pieces.

Avoiding Other Sources of Sulphur

In addition to the fuel, there are a few other sources of sulphur that must be considered and provided against.

Scale and other accumulations on the hearth may contain sulphur. To prevent contact with this, the metal should be supported above the hearth on rails or other convenient shapes.

All sulphate salts and sludge remaining from a sulphuric-acid pickling operation should be removed completely by washing before heating the metals. If sulphates are allowed to remain, the sulphur present in them will affect the high-nickel materials at furnace temperatures.

Marking paints are seldom suspected as sources of sulphur, yet they usually contain metallic sulphide pigments. It is advisable to remove all marking paint before heating, to avoid possible embrittlement of the painted areas.

Heating Temperature

Monel, nickel and Inconel show important differences among themselves as to proper forging temperatures, particularly in the upper safe heating limits and in tendencies toward red-shortness. The approximate temperature ranges for hammer forging, die forging and bending are shown graphically in Fig. 4.

While heating the high-nickel materials, the furnace should be maintained at a temperature somewhat higher than that at which the work is to be "pulled," and in no case should it be pulled at less than 1,100° C. The practice employed in some shops, of carrying the furnaces at excessively high temperatures in order to reduce the heating time and speed up production, is damaging to nickel and high-nickel alloys. Results following from the use of correct and incorrect heating temperatures are illustrated in Fig. 5.

Many shops heat nickel and its alloys successfully without pyrometers or automatic temperature control, but it is wise to provide these facilities. In their absence those who have had little or no experience with the high-nickel materials should make preliminary trials on scrap pieces, so that they can gauge the proper forging temperatures by colour before attempting to work the stock. A useful



Fig. 5.—The Monel bar at the left was heated to a temperature above the safe limit for forging. The bar at the right was heated to about 1,175° C., which is within the safe forging range.



Fig. 7.—Hammer-forged Monel hooks used for moving large pickling crates and other heavy loads.

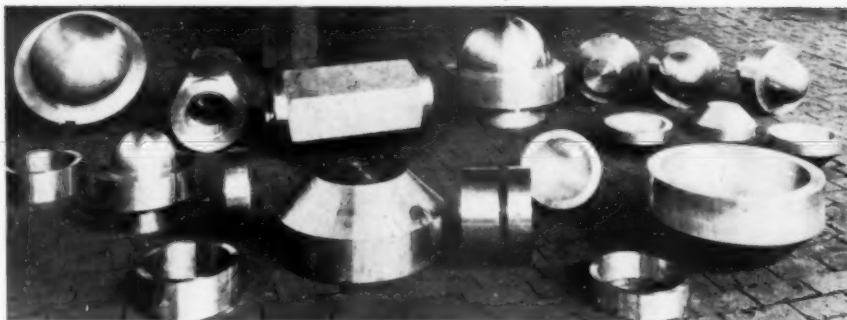


Fig. 8.—A group of machined Monel hammer forgings.

bend test is described later under the sub-heading, "Checking, heating conditions and forging temperatures."

Time of Heating

The proper length of time to heat Monel, K Monel, nickel and Inconel is the minimum required to heat the piece uniformly through. It is bad practice to expose these materials to combustion gases in a heating furnace for long periods after the pieces have reached a uniform forging temperature. Where a delay in forging is met, as in a major breakdown, the heated pieces should be withdrawn from the furnace and reheated later when operations are to be resumed.

It is not possible to give an inflexible set of rules to govern the time of heating, because furnaces and furnace operation vary so widely. Rough approximations of the total elapsed time desirable between charging and pulling the materials are shown graphically in Fig. 6.

Short slugs receiving heat from all sides require from 30 to 50% less time. Flat slabs and plates require from 50 to 100% additional time.

When the furnace is to be charged with several pieces of metal, the work should be so scheduled that each piece will be pulled as soon as it is heated uniformly to temperature, at which time it may be replaced by a cold piece. The charging of the work in a manner to reduce "soaking" time to a minimum must take precedence over volume of production if good work is to be done.

In heating for small drop forgings, weighing, say, 5 lb. or less, or for upsetting bar ends for rivets and bolts, a small number of pieces should be charged at the start and, whenever a piece is pulled, it should be replaced by a cold piece. The number of pieces to be charged at the start will be determined by the time required to bring a piece to the forging temperature, and by the number of pieces to be forged in a unit of time. For example, in hot heading $\frac{3}{4}$ in. diam. nickel rivets at a rate of three per minute, or 20 seconds per rivet, the bar end may require 10 minutes in the furnace to reach the proper forging temperature, and hence the rate of forging will be 30 times the rate of heating. If 30 pieces be charged, the heading machine can be started working steadily after 10 minutes, but the last piece will have been ready for forging 10 minutes before it is pulled. Obviously, if 60 pieces be charged, the last piece pulled

will be at temperature for 20 minutes. The nickel alloys cannot be heated successfully in this manner. The right method for the above conditions is to charge three rods per minute. After 10 minutes' heating the first rods will be ready, and as one is pulled a cold piece can be charged. The heading machine can then be put into steady operation.

Larger work, which may require 20—30 or more minutes to reach the desired temperature, and perhaps a minute to forge, should be charged in the manner outlined above.

The furnace capacity in some shops is inadequate to keep the hammer or heading machine in steady operation. This is especially noticeable with nickel, for which the flame temperature must be lower than for steel, which means a longer time required to bring the metal to forging temperature. Therefore, the production per machine will necessarily be less than when forging steel.

Furnace Atmospheres and their Control

The atmosphere which matters is that in the immediate vicinity of the work, which means, in practice, the gases of combustion sweeping over the metal surface. This atmosphere should be free from sulphur, because at a dull-red heat and upwards sulphur is readily absorbed into the metal surface with the formation of nickel sulphide which produces surface embrittlement. The tendency to absorb sulphur from sulphur-containing furnace gases is more pronounced in a reducing atmosphere than in a slightly oxidising atmosphere. If the fuel contains sulphur it is necessary to work the furnace slightly oxidising and to risk a certain amount of scaling, rather than to operate with a reducing atmosphere.

In heating for forging, however, it is desirable to avoid scaling, and therefore, provided sulphur-free fuel is available, the atmosphere should be adjusted so as to contain 2% or more carbon monoxide and free carbon. The atmosphere should not be permitted to alternate from reducing to oxidising. The slightly reducing condition desired is obtained by cutting down the air supply until there is a tendency to smoke, which indicates an excess of fuel and a reducing atmosphere. Then the air supply should be increased slightly so as to give a hazy atmosphere or a soft flame. There is no upper limit to the permissible amount of carbon monoxide or free carbon that may be present, as the metals, unlike steels, are not subject to carburisation. A slight excess of fuel over air is all that is required, and the closer the atmosphere to the neutral condition the easier it is to maintain the required tempera-

Fig. 9.—Drop-forged Monel disc for high-pressure steam safety valve. Trimmed die-forging on left; finished part on the right.

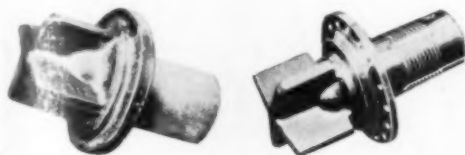


Fig. 10.—Drop-forged Monel links for conveyer chairs used in pickling equipment.



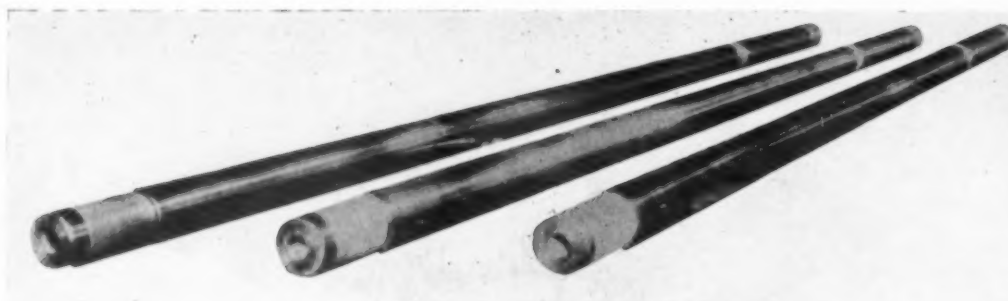


Fig. 11.—Forged Monel gate stems (6 in. diameter by 18 ft. 4 in. long) hammered below the usual forging temperature to obtain higher strength.

ture. The true condition of the atmosphere may be determined by analysing gas samples taken at various points about the metal surface.

The stack dampers should be wholly or partially closed in order to force the gases out under the furnace door, where the excess of unburned fuel will burn freely. The pressure set up in this manner prevents the entrance of air under the door or through the slot.

Care should be taken to bring the furnace up to the upper limit of the forging range before introducing the

having oil burners set in the back or end walls. Both the combustion and heating are done in the space above the hearth, which, in many cases, is not sufficiently large to ensure the proper combustion of fuel oil. In such furnaces a large portion of the oil is gasified by impingement on the hot metal, which places the metal directly in the combustion zone. This is deleterious to Monel, nickel, Inconel and other high-nickel alloys. If furnaces of this type must be used, it is necessary to protect the work in an appropriate manner as by shielding it with steel plates, placed so as to prevent the unburned fuel from coming in contact with the hot metal.

When the amount of work to be done is large, consideration should be given to modifying the furnace so as to be sure that no unburned fuel strikes the hot metal. This may be accomplished by setting the burners back and firing through a tunnel, or by tilting the burners so that the flame is directed against the roof and opposite wall. Other methods may be necessary, depending on local conditions.

Checking Heating Conditions and Forging Temperatures

Before charging work to the furnace it is advisable to check the correctness of the heating conditions. A test can be made readily by heating a bar of convenient size, say $\frac{1}{2}$ in. diam. round rod or $\frac{1}{2}$ in. \times 1 in. flat bar, to the required temperature and holding it in the furnace for 10 to 15 minutes at temperature. The piece is then either water-quenched or air-cooled and bent, after cooling, through 180° flat on itself. There will be no sign of cracking if the conditions of heating have been correct. The extent of any damage that may have occurred is judged by the depth of the cracks.

If the operator has had no previous experience with the high-nickel materials, and facilities are not provided for temperature control, it is advisable for him first to practise drawing out bars under the hammer, taking care to preserve square edges, and then to make bend tests, to familiarise himself with the temperature range in which the metals may be forged safely. Bend tests are made best on bars approximately 1 in. \times $\frac{1}{2}$ in. \times 6—8 in. long. A good practice is to change several of these test-pieces into the furnace at a time and pull single bars at various temperatures as they are being heated up. Each bar is then bent immediately through a 180° bend. This may be started in a "vee" block and finished by flattening down under the hammer, or the bending may be done by hand. This



Fig. 12.—Location of the test-pieces in sample of 6 in. diameter gate shaft shown in Fig. 11. The results of these tests are given in Table II.

parts which are to be heated. Once the furnace attains the full temperature, it should be adjusted so as to maintain the temperature with complete combustion close to the burners, and without any possibility of combustion taking place on the surface of the metal. The furnace must, therefore, be designed to provide sufficient combustion space to enable the fuel to be completely burned before the gases strike the metal.

Oil requires more space than most gas fuels, and therefore aml e height above the hearth and depth between the work and the back wall of the furnace should be provided in order to facilitate completion of combustion before the flames strike the work.

Most forge shops are equipped with slot-type furnaces

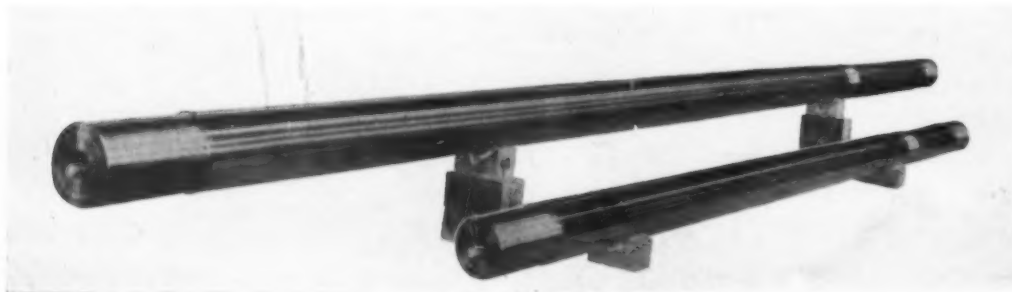


Fig. 13.—Hammer-forged, heat-treated, and machined K-Monel stems for the Tygart River Dam. The shorter stem is 6 in. diameter by 12 ft. 9 in. long; the longer stem is 7 in. diameter by 18 ft. 5 in. long. The physical properties are given in Table III.

work must be done as rapidly as possible to avoid an excessive drop in temperature while the piece is being bent. When the forging temperature is correct there will be no sign of cracking at the sharp corners.

Forging and Bending

There will be little difficulty in forging or bending any of the three materials after they have been heated properly, and so long as the working temperature ranges shown in Fig. 4 have been observed. The operator will find that the metals are considerably stronger and stiffer than steel at forging temperatures, and for this reason a machine worked at full load to produce a given steel forging may be incapable of producing the same forging in nickel or the high-nickel alloys. It may be necessary, for some forgings, to use heavier hammers and larger machines for the nickel alloys than would normally be used in forging steel. This applies particularly to single-blow operations, as in heading rivets and bolts, and in pressing.

K Monel requires special mention under this heading, because while the general forging procedure and temperature ranges are similar to those already described for ordinary Monel, it must be remembered that K Monel is a heat-treatable alloy. Consequently, if it is allowed to air cool from the forging temperature it may be found to be too hard for cold-forming or working in later operations such as machining.

The following should therefore be noted:—

1. If it becomes necessary to reheat the metal in order to complete the work, the metal should be recharged in the furnace with a minimum of delay.

2. When hot-working has been completed, or when it is found necessary to allow the metal to cool before further hot-work, the metal should not be allowed air cool but should be quenched from 790° to 800° C., or above. The preferred quenching medium is water, to which about 2% by volume of alcohol has been added. Unless it be quenched, the piece will self-heat-treat to some extent on cooling and set up stresses that may result in cracks or in surface tears either during cooling or during subsequent heating.

3. K Monel which has been allowed to air cool from around 700° C., instead of having been quenched as described above, may be too hard for practical cold-forming or working later.

4. It is not advisable to attempt to increase the strength and hardness of K Monel forgings by subjecting them to semi-cold forging. Such operations are likely to result in damage to the material, due either to forging in the range of low ductility or to the possible effects of self-heat-treatment. There is no practical advantage to be gained since, after heat-treatment, the properties of a hot-finished and a semi-cold-finished forging will be essentially the same.

Dies and Lubrication

Die blocks for drop forgings or pressings may be made from either straight carbon or alloy steels. The choice between carbon steel and one of the several excellent alloy die steels available will depend largely on the shape and size of the piece, the quantity to be produced, and the material. Dies of 0.80% carbon steel, hardened and tempered to 60 scleroscope, can be expected to give a good life on the smaller forgings in nickel and Monel. There is no point in heat-treating carbon steel dies above 60 scleroscope, as the heat of the hot metal being forged will always reduce the hardness to 60 scleroscope and may crack the die. Monel forgings up to 15 in. in length are produced in 0.80% carbon steel dies heat-treated to 60 scleroscope. The yield is 3,000 to 5,000 pieces per die.

Alloy steel dies meet the needs of modern production better than do carbon-steel blocks, and their use is almost a necessity for the larger or more intricate shapes in Monel or nickel, and for all forgings in Inconel, except small, simple shapes.

Trimmer dies should be made of high-speed steel, with the cutting edge ground to a considerable rake. They

should be set up closely enough to cut tissue paper. The trimming may be done either hot or cold.

There is a slightly greater tendency toward sticking in the die with the high-nickel materials than with steel, especially with difficult shapes. A swab with a mixture of heavy grease and graphite ensures proper clearing of the work from the die. Sawdust thrown into the die is also useful in preventing sticking.

Physical Properties of Forgings

The physical properties of forgings made from Monel, nickel and Inconel are given in Table I. The tensile strength and yield point values will be closer to the higher values shown when forging is carried out in the lower parts of the temperature ranges recommended. The strength of hammer forgings may be improved materially by judicious hammering after the material has cooled to 650° C. This is illustrated in the values listed in Table II for the large, high-strength, forged Monel sluice-gate stems for Madden Dam, shown in Fig. 11. The original locations of the individual test-pieces of Table II, in the forged bar, are shown in Fig. 12.

TABLE I.
PHYSICAL PROPERTIES OBTAINABLE IN MISCELLANEOUS FORGINGS.

	Monel.	Nickel.	Inconel.
Tensile strength, tons/sq. in.	34—42	28—40	38—45
Yield strength (0.5% set), tons/sq. in.	15—22	10—18	15—22
Elongation % in 2 in.	40—25	40—25	40—25
Reduction of area (%)	70—50	70—50	70—50
Brinell (3,000 kilogs.)	120—180	100—150	125—180

The unusually good properties obtainable in heat-treated forgings of K Monel are given in Table III, which gives the values shown by test-pieces taken from the hammer-forged, K-Monel gate stems made for the Tygart River Dam, shown in Fig. 13. Forgings of K Monel are heat-treated by holding at 580° to 600° C. for 6 to 8 hours after the entire mass of metal has attained uniform temperature.

TABLE II.
PROPERTIES OF FORGED MONEL GATE STEMS FOR MADDEN DAM.

Test Piece No.	Yield Strength, Tons/sq. in.	Tensile Strength, Tons/sq. in.	Elongation in 2 in. %.	Reduction of Area %.
1	33	44	34.5	60.4
5	33	45	33.6	60.4
6	32	44	33.6	60.4
2	34	46	32.8	60.4
3	34	45	34.5	57.9
4	35	45	33.6	59.8
7	32	44	35.5	63.6
9	34	45	34.5	63.1
8	34	45	30.1	65.0
10	34	45	36.0	63.1
11	34	45	34.0	61.8

TABLE III.
PROPERTIES OF FORGED AND HEAT-TREATED K-MONEL GATE STEMS FOR TYGART RIVER DAM.

Proportional elastic limit	40 tons/sq. in.
Yield strength (0.5% set)	49 "
Tensile strength	68 "
Elongation, 2 in.	24.7% "
Reduction of area	41.6 "
Brinell hardness	297
Rockwell (C) hardness	29.5

LANCASHIRE firm of engineers require at once a specialist in heat treatment to help in the layout and subsequently to control modern heat treatment department. Applicants must have first class technical as well as practical experience in the heat treatment of tool and alloy steels. Replies stating age, qualifications, experience and salary required to be addressed to Box No. 106.

Reviews of Current Literature

The Iron and Steel Industry

THE title of this book is so comprehensive and its scope so great that a library of works has been published covering the numerous aspects of the subject, from the highly technical treatise, giving data and detailed information of direct value to those engaged in the industry, to those books that deal with the subject superficially and in such a way that they have an interest for the layman. The present work gives what can be regarded as a comprehensive outline of the industry, since the treatment is broad rather than detailed; it provides, therefore, an introduction to the more detailed technical works available on the many different aspects of a vast subject.

In the preparation of this work it is probable that the main problem which confronted the authors was not so much what should be included in the book, but what should be cut out to effect brevity and yet maintain a sound framework. Yet the authors have been successful in embracing the whole span of this basic industry, from an outline of its history, in which developments from the middle ages to the present time are briefly described, to brief information on the structure of iron and steel and the effect of heat-treatment on the physical properties of steel. Materials used and various sources of supply are discussed; chapters are given to the blast-furnace, to the work in the foundry, and the manufacture of wrought iron. The various steelmaking processes are briefly described, including the cementation and crucible processes, the Bessemer process, the open-hearth process, and electric steelmaking. A chapter is allocated to the mechanical treatment of steel, embracing rolling and tube mills, forging, pressing and wire drawing. Some attention is given to alloy steels, and the location of the iron and steel industry is briefly discussed.

The book is well written and carries some excellent illustrations of British iron and steel plant; it is admirably suited to the needs of engineering students, and especially to those engaged on the commercial side of the industry, to whom basic information on the subject should be regarded as essential. As an introduction to the many different branches of the industry the book fulfils its purpose adequately.

By G. A. BROWN, B.A., and A. L. ORFORD. Published by Sir Isaac Pitman and Sons, Ltd., Kingsway, London, W.C. 2. 122 pp. Price 6s. net.

Specifications for Aluminium and Aluminium Alloy Products

IN most countries where aluminium and its alloys are produced the problem of standardisation has become increasingly difficult, because of the rapid development and increase in numbers of the alloys available, but standardisation was soon recognised as essential, not only to ensure adequate control in processing operations, but also as a check on quality and performance in service. Considerable success has been achieved in the standardisation of aluminium and its alloys in Britain, and recognised alloys have been developed that fulfil the requirements of the great number of specifications published by the British Standards Institution and H.M. Stationery Office.

The development and standardisation of improved aluminium alloys and their manufacture have made possible new applications and are responsible, in a large measure, for the rapid increase in the consumption of aluminium during recent years. Since the beginning of hostilities, however, the products of the aluminium industry have been directed more particularly to work of national importance, and, because of the greater number of works engaged, standardisation has been invaluable. But the range of specifications is relatively large, and to meet a widely felt want, the technical staff of the Northern Aluminium Co., Ltd., have compiled a fully classified summary of current D.T.D. and B.S. Specifications relating to aluminium and aluminium alloy products, which will be especially useful to all engaged in working to light alloy specifications.

The full range of British light alloys as specified at present is classified according to the various forms in which each is produced—namely, ingot, sheet and strip, bars and sections, tubes, wire and rivets, forgings and castings. The appropriate D.T.D. and B.S. Specifications are shown under each heading, with the proprietary nomenclature and tables of chemical composition and mechanical properties. A tabulated summary of proprietary alloys in alphabetical order, showing the corresponding specifications and the forms of material to which they apply is also given.

This book provides a ready reference for technical personnel in the numerous manufacturing concerns now working for the first time on light alloy materials to standard specifications. It is comprehensive, of convenient size and admirably produced, and a copy may be obtained free on application to the Research and Development Department of the Northern Aluminium Co., Ltd., Banbury.

The Manufacture and Use of Cemented Carbides

THE application of cemented carbides has made great progress since their inception, due largely to the development of proper technique and also to improvements effected in manufacture. Although it would seem that a large number of metal alloys and other compounds, such as carbides, borides and nitrides, may be used in the manufacture of these hard alloys, the selection of suitable constituents is actually limited for many reasons.

Useful information on the manufacture and use of cemented carbides is given in a brochure issued by Thos. Firth and John Brown, Ltd., Sheffield. It is the paper read before the Institute of Production Engineers by H. Burden, B.Sc., of the Brown-Firth Research Laboratories, and deals with the cold-press process of manufacture, the nature of the constituents, structure, the sintering process, steel-cutting carbides, the manufacture of tools and grinding procedure, the application of carbide alloys, tool design, and the importance of rigidity of tool and machine; it also includes many examples from present-day practice. Those interested in the use of carbide alloys will find this brochure of special value.

Forthcoming Meetings

INSTITUTE OF METALS.

BIRMINGHAM SECTION.

Dec. 12. "The Casting of Brass Ingots," by N. F. Fletcher. MANCHESTER METALLURGICAL SOCIETY.

" 11. "Heat-treatment in Salt Baths," by W. Nelson. THE INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND.

" 17. "Ship of the Future," by A. C. Hardy, B.Sc. NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

" 17. Sir Charles Parsons Memorial Lecture: "The Engining of Highly-powered Ships," by Sir Stephen J. Pigott, D.Sc.

INSTITUTE OF BRITISH FOUNDRYMEN.

EAST MIDLANDS BRANCH.

Nov. 16. "The Randupson Process of Cement Moulding," by F. W. Rowe, B.Sc. At Derby.

Dec. 14. "Miscellaneous Developments in Foundry Refractories," by E. J. Crawley. At Derby. LANCASHIRE BRANCH.

" 7. "The Foundry—Past, Present and Future," by F. Dunleavy.

LONDON BRANCH.

" 11. "Aluminium Bronze," by C. H. Meigh. Joint Meeting with Institute of Metals.

SCOTTISH BRANCH.

" 14. "Observations on Contraction in Cast Iron," by E. Loogden, A.M.I.Mech.E.

FALKIRK SECTION.

Nov. 30. "This and That," by T. Tyrie, B.Sc.

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Dec. 14. Discussion on the Report of the Melting Furnaces Sub-Committee, to be opened by F. K. Neath, B.Sc.

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METALLURGIA.

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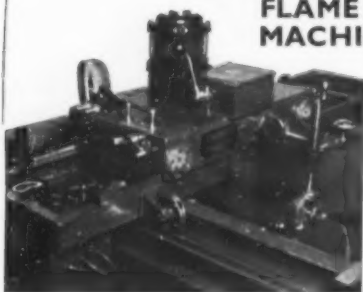
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